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What are metal prices like?

Co-movement, price cycles and long-run trends

Anja Rossen*

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Abstract

This study explores the dynamics of monthly metal prices during the past 100 years. On the basis of a unique data set, co-movement, price cycles and long-run trends are analyzed by means of common statistical methods and the results are compared to the findings in the literature. Due to its large number of monthly observations (1224) and high number of price series (20), this data set has a huge advantage. Findings suggest that some results in the literature are specific for non-ferrous and precious metals and do not necessarily carry over to other metals like steel alloys, electrical metals, light metals, steel or iron ore. However, other results in the literature can be confirmed by the analysis of this comprehensive data set.

Keywords: metal prices, co-movement, price cycles, super cycles
JEL: C41, E32, Q31

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1 Introduction

Metals are not only important for producing countries but also for consumer countries because they are a key input factor in many industries. Therefore, the dynamics of commodity prices are of high relevance for worldwide economic activity (e.g., Labys 2006), e.g., export earnings from metals are often the main source of revenue for some developing countries. Accordingly, commodity price fluctuations may have a major impact on overall macroeconomic performance and living standards in these countries (e.g., Deaton 1999, Cashin et al. 2002). Furthermore, companies which process raw materials can be negatively affected by drastic price increases because they suffer from higher input costs. The recent rise of emerging markets puts upward pressure on commodity prices. Technological shifts and significant improvements in the extraction of minerals put downward pressure on commodity prices. Nevertheless, price divergence is limited to some extent because certain metals are substitutes (e.g., platinum and palladium) in the consumption and the production of other goods (Lombardi et al. 2012, Hammoudeh & Yuan 2008). Overall, price volatility creates uncertainty among producers, consumers and stockholders. Improving our understanding of commodity price developments and its short and long-run price drivers may also help to better forecast commodity prices (Arezki et al. 2014). Thus, a precise examination of commodity prices, their long and short-term cyclical behavior, and their co-movement is essential for economic planning and forecasting purposes.

The significant increase in commodity prices between 2000 and 2008 renewed interest in modeling their behavior (e.g., Humphreys 2010, Radetzki 2006). Due to the rapid growth of the emerging markets, worldwide demand for commodities has increased dramatically. Because of their variety of industrial uses and investment purposes metals play an important role in the construction industry, the electrical industry and the automotive manufacturing among others. They constitute an important subset of non-agricultural and non-fuel commodities closely linked to worldwide business cycles (e.g. Cashin et al. 2002, Akram 2009, Lombardi et al. 2012, Erten & Ocampo 2013) and monetary issues (e.g. Frankel 2008, Palaskas & Varangis 1989, Hammoudeh & Yuan 2008, Arango et al. 2012, Grilli & Yang 1981). More recently, China and other emerging markets have become the dominant factor on the metal markets (Belke et al. 2013). For example, China was the top importer of copper, nickel and tin in 2012 (UN 2014) and at the same time the biggest producer of a number of important metals.

In general, commodity prices are assumed to follow common trends (e.g., Palaskas & Varangis 1991, Jerrett & Cuddington 2008, Roberts 2009, Byrne et al. 2013), feature sharp price peaks in the short-run (e.g., Deaton & Laroque 1992, Cashin & McDermott 2002) and exhibit asymmetric cycles, i.e. slump phases last longer than boom phases (e.g., Cashin et al. 2002, Roberts 2009). In addition, metal price fluctuations over the last 150 years are characterized by three major super cycles that lasted between 20 and 70 years. According to Cuddington & Jerrett 2008 and Jerrett & Cuddington 2008, a fourth super cycle that began in 1999 is underway. Price movements are driven by macroeconomic fundamentals like worldwide industrial production, the oil price, interest and exchange rates (e.g., Palaskas & Varangis 1989, Leybourne et al. 1994, Byrne et al. 2013, Lombardi et al. 2012 Vansteenkiste 2009, Hammoudeh & Yuan 2008). Findings suggest, however, that price peaks are triggered by demand shocks rather than by metal specific supply shocks (e.g., Akram 2009, Labys et al. 1999).

By investigating co-movement, short- and long-run price cycles, this study examines the dynamics of monthly price series of a variety of mineral commodities during the past 100 years. Therefore, a unique data set is created which includes twenty time series from the following five metal groups: non-ferrous metals (copper, zinc, tin, lead), precious metals (gold, silver, platinum, palladium), steel alloys (chromium, cobalt, manganese, molybdenum, nickel, tungsten), light metals (aluminum, magnesium), and electrical metals (antimony, bismuth). Steel and iron ore prices are also included in the data set. Co-movement, short-run cycles and super cycles are analyzed by means of common statistical methods and compared to the results in the literature. Thus, the methodological approach of this study is closely related to the work of Cashin et al. (2002) and Roberts (2008) for short-run cycles and Cuddington & Jerrett (2008) for super cycles. Compared to earlier studies which are mostly restricted to the last 50-60 years or are based on yearly data frequency, this analysis has the major advantage that a large number of monthly observations spanning a wide variety of metals is being considered. The data set also includes a number of metal series that have not previously been considered in the literature. Aim of this paper is to determine whether the findings for major metals (e.g., zinc, tin, aluminum and copper) which are traded on the London Metal Exchange (LME) can be confirmed for this comprehensive data set and the larger time period under consideration.

The results suggest that a number of findings in the literature are specific for non-ferrous and precious metals. This is especially true for short-run cycles and co-movement. Although metal prices have become more synchronized over the past 100 years, co-movement is not a general phenomenon. Seemingly related metals strongly co-move, as indicated by the correlations coefficients that are stronger within metal groups than between them. Considering other metals like steel alloys, light metals or electrical metals, the results may be different. Additionally, price cycles are asymmetric. The average time spent in slump phases is longer than the average time spent in boom phases and slump phases significantly last longer than boom phases (on average). The number of cycles varies significantly depending on the specific metal under consideration. Overall, non-ferrous metal prices exhibit the greatest number of completed cycles. No evidence of duration dependence can be found. Hence, the probability of a phase ending is independent of the duration that a time series has already spent in this phase. Furthermore, there is no significant correlation between the amplitude and the duration of cycle phases. Regarding long-run trends of metal prices, this study confirms the results in the literature. Metal prices can be characterized by four super cycles, evident during the last 100 years. Additionally, the long-run component of metal prices considerably varies over the set of mineral commodities: multiple changes in the sign of the long-run component are very common.

The rest of the paper is organized as follows. The next section provides a brief overview of the empirical literature on commodity prices behavior. Section 3 describes the data and section 4 the econometric analysis. The results are discussed in section 5 and section 6 concludes the paper.

2 Literature

Commodity prices are assumed to follow common trends (e.g., Palaskas & Varangis 1991, Jerrett & Cuddington 2008, Roberts 2009, Byrne et al. 2013), feature sharp price peaks in the short-run (e.g., Deaton & Laroque 1992, Cashin & McDermott 2002) and exhibit asymmetric cycles (e.g., Cashin et al. 2002, Roberts 2009). In addition, metal price fluctuations over the last 150 years are characterized by three major super cycles. A fourth super cycle that recently began in 1999 is underway (Cuddington & Jerrett 2008, Jerrett & Cuddington 2008). This section provides a brief summary of the empirical literature on commodity prices behavior and the macroeconomic determinants that are assumed to drive commodity price movements and trigger sharp price peaks.

The tendency of different commodity prices to move together is called co-movement. This common tendency is the result of supply and demand shocks that affect several prices simultaneously and/or from spill over effects from one metals market to another (Labys et al. 1999). Findings suggest that co-movement is more likely to be present if prices are driven by demand rather than by metal specific supply shocks (Jerrett & Cuddington 2008). Moreover, metals are co-produced (e.g. nickel and copper, see Cashin et al. 1999) and/or substituted in consumption (e.g., platinum and palladium, see Hammoudeh & Yuan 2008). Therefore, price divergence is limited to some extent. Cashin et al. (1999) apply simple correlation and concordance analysis in order to measure the extent to which two time series (agricultural and raw materials) are synchronized. Their findings suggest that co-movement is not a general phenomenon. Nevertheless, they find a certain amount of co-movement between seemingly related metals (copper, gold, aluminum, lead, tin, zinc). Roberts (2009) defines co-movement similarly, namely as the percentage of two price series spent in the same cycle phase (booms or slumps). He concludes that metal prices (aluminum, copper, lead, iron ore, zinc, silver, platinum, tin, mercury, ferrous scrap) strongly co-move. Numerous studies deal especially with gold and silver prices. Results suggest, that the long-run connection between gold and silver prices depends on the specific time period under consideration (Baur & Tran 2014). Accordingly, gold and silver prices became more separated over time (Escribano & Granger 1998). Nevertheless, gold and silver prices seem to be closely linked in the short-run (Soytas et al. 2009, Hammoudeh et al. 2011).

Pindyck & Rotemberg (1990) triggered a discussion on the excess co-movement of commodity prices. Seemingly unrelated prices follow a common trend that cannot be explained by macro variables like industrial production, inflation, interest or exchange rates. By using monthly agricultural (i.a. wheat, cotton) and metal (copper, gold) prices, they demonstrate that co-movement is well in excess of what can be explained by macroeconomic fundamentals. They relate this phenomenon to irrational trading and herding behavior of financial market participants. The literature that followed is quite extensive and draws different conclusions with respect to the excessiveness of commodity price co-movement. For example, Palaskas & Varangis (1991) apply cointegration tests and error correction models. Their findings indicate a strong relationship between different commodities but they do not find any evidence for excess co-movement. They do, however, suggest an alternative explanation. Traders may misinterpret a commodity specific supply shock for a macro shock that affects a variety of metals simultaneously. Traders immediately react by going short or long on certain commodity markets and adjusting their position as new and correct information becomes available. In this context, excess co-movement is an exception rather than the rule. Leybourne et al. (1994) compare Pindyck & Rotemberg (1990) and Palaskas & Varangis (1991) approaches and conclude that excess co-movement cannot be observed over a wide range of commodities. According to them, another possible explanation for excess co-movement could be the omission of important macroeconomic variables. Other authors either find weak (Deb et al. 1996, Labys et al. 1999) or no evidence (Deb et al. 1996, Lescaroux 2009, Vansteenkiste 2009) of co-movement in excess of macroeconomic fundamentals.

In analyzing the dynamics of metal price movements it is important to know the macroeconomic fundamentals that potentially drive prices. These variables may affect a number of metals simultaneously such that its prices move together.[1] The macroeconomic variables that potentially drive commodity prices are industrial production, oil prices, interest rates and the US dollar exchange rate (e.g., Palaskas & Varangis 1989, Leybourne et al. 1994, Byrne et al. 2013, Lombardi et al. 2012 Vansteenkiste 2009, Hammoudeh & Yuan 2008). While metal supply is relatively price inelastic in the short-run, demand quickly adjusts in response to the business cycle (Labys et al. 1998). Thus, via an increase of worldwide demand, a shift in industrial production leads to higher commodity prices (e.g., Pindyck & Rotemberg 1990, Issler et al. 2014). A lower interest rate level increases speculative demand for storable commodities (investors shift out of money into commodities), raises commodity carrying costs and leads to higher supply by boosting the incentive for extraction today rather than in the future (e.g., Pindyck & Rotemberg 1990, Arango et al. 2012, Hammoudeh & Yuan 2008). Accordingly, commodity prices rise in response to falling interest rates (Frankel 1986, Frankel 2008). Simultaneously, global liquidity raises commodity demand by threatening financial stability and future asset prices (Belke et al. 2010). Hence, monetary expansion leads to higher commodity prices via an increase of speculative demand (e.g., Belke et al. 2013, Batten et al. 2010, Grilli & Yang 1981).

Since commodity prices are normally denominated in US dollars, its exchange rate may be a factor that relates different commodity prices to each other (Sari et al. 2010). On the one hand, commodity exporters may raise prices in times of a weak US dollar in order to correct their purchasing power. On the other hand, a weaker US dollar temporarily leads to lower commodity prices and hence raises their demand such

[1] Nevertheless, this study does not particularly focus on the macroeconomic determinants of metal prices movements in this study. Such a detailed analysis would be beyond the scope of this work and is left for future research.

that prices rise again (Lombardi et al. 2012). Studies show that the US Dollar is able to explain a fairly stable proportion of the variance of commodity prices in the short-run (e.g., Reinhart & Borenzstein 1994, Lombardi et al. 2012, Sari et al. 2010). Finally, the oil price may affect other commodity prices due to cost repercussions because the production of certain metals (e.g., aluminum) is very energy intensive (e.g., Akram 2009, Vansteenkiste 2009, Baffes 2007).

Overall, economic activity seems to be the dominant influence on the metal markets (e.g., Akram 2009, Labys et al. 1999). Price peaks are more likely to occur in response to demand shocks than supply shocks (e.g., Labys et al. 1999, Brunetti & Gilbert 1995). However, several authors also stress the importance of supply as the key driver of commodity prices (e.g., Cashin et al. 2002, Fama & French 1988).

Another direction of research investigates the cyclical behavior of commodity prices, either in the short run or in the long-run (super cycles). Thereby, co-movement can be either measured by the length of time that two price series spent in the same cycle phase or by the degree to which its super cycle components are correlated. Short-run price cycles usually vary from two to eight years and are assumed to be asymmetric. Accordingly, times of falling prices (slumps) last longer than times of rising commodity prices (booms) (e.g., Cashin et al. 2002, Roberts 2009). Asymmetric cycles occur due to the existence of different market participants like traders, speculators or hedge fund managers. All of these form different expectations, strategies and preferences in response to positive or negative shocks which can result in different speeds of adjustment to the long-run equilibrium (Hammoudeh et al. 2010). Findings regarding the duration dependence of price cycles are rather mixed. While Davutyan & Roberts (1994) find weak evidence for positive duration dependence, Cashin et al. (2002) conclude that the probability of a boom (slump) ending is independent of the time that is already spent in this boom (slump). Additionally, no significant connection between the amplitude and the length of a phase can be found (e.g., Roberts 2009). Regarding the cyclical behavior of metal prices, different authors draw different conclusions. Depending on the specific time period under consideration, either zinc (Cashin et al. 2002, Roberts 2009) or copper (Davutyan & Roberts 1994, Labys et al. 1998, Labys et al. 2000) exhibits the most cycles. The average duration of boom and slump phases also significantly varies from study to study. Nevertheless, these studies usually consider a relatively small number of metals and/or a shorter time period.

Long-run price cycles are called super cycles and typically vary between 20 and 70 years, driven by steady expansions of worldwide demand (Cuddington & Jerrett 2008). Metal price movements during the last 150 years are characterized by three major super cycles: 1890-1911, 1930-1951 and 1962-1977 (Cuddington & Jerrett 2008, Jerrett & Cuddington 2008). A fourth super cycle that began in approximately 1999 is underway. Similar results are found by Erten & Ocampo (2013) based on a comprehensive metal price index: 1885-1921, 1921-1945, 1954-1999, 1999-ongoing. While earlier super cycles were mostly driven by the industrialization and urbanization in Europe, the United States and Japan, this ongoing cycle is caused by China's rapid growth (Cuddington & Jerrett 2008, Farooki 2010). In 2008, Jerrett & Cuddington extended their super cycle search (Cuddington & Jerrett 2008) to steel, pig iron and molybdenum prices. They apply simple correlation and principal component analysis in order to investigate the co-movement of these related metals and find evidence in favor of strong co-movement.

To sum up, the literature review bares a number of open questions regarding the price dynamics of mineral commodities: Do metal prices generally comove or is this a phenomenon that is only valid for non-ferrous and precious metals? Is the extent to which metal prices comove changing over time? Finally, this study will contribute to the question whether price cycles are the same over a variety of mineral commodities, either in the short or in the long-run.

3 Data Description

The following analysis is based on a data set that contains 20 time series over the past 100 years. Most series span the period between January 1910 and December 2011, for a total of 1224 monthly observations. The prices of nine metals are not available for the whole period. For a detailed description of the data set, see Table A.1 in the Appendix. The length of the data set[2] is hugely advantageous in comparison to earlier studies on monthly commodity prices which are mostly restricted to the history of the last 50-60 years or are based on yearly data frequency. Furthermore, a much larger number of mineral commodities is being considered: non-ferrous metals (copper, lead, tin, zinc), precious metals (gold, palladium, platinum, silver), steel alloys (chromium, cobalt, manganese, molybdenum, nickel, tungsten), light metals (aluminum, magnesium), and electrical metals (antimony, bismuth). Steel and iron ore prices are also included in the data set.

[Insert Table 1 here.]

The summary statistics in Table 1 mostly confirm the results in the literature regarding non-normality, high first-order autocorrelation and heteroscedasticity of commodity prices (e.g., Deb et al. 1996, Labys et al. 1999). Due to heavy tails (outliers), the normality assumption is strongly rejected for almost all series. Although the assumption of homoscedasticity is rejected for the majority of series, no volatility clusters can be identified in the series and the rejection is attributed to the observed outliers. Nonetheless, certain

[2] In order to obtain such long time series, various price information from different sources had to be combined. For example, the aluminum price series was obtained from three different sources and contains four specification/market breaks (New York, London Metal Exchange, 98 % - 99.7 %), two distinct weight units and two currency values (¢/lb and US$/metric ton). First, all prices were converted into uniform weight units and currency values. Next, further breaks that were based on different markets or metal specifications were eliminated by combining two consecutive series based on overlapping time series values. Particular attention was paid to ensure that the various definitions/specifications are consistent and comparable over time. Starting from the current edge, a factor for each break was calculated. Finally, nominal price series were deflated by means of the US Consumer Price Index (2011=100) by the U.S. Department of Labor and logarithms were taken.

statistics do not confirm the results in the literature (non-stationarity, negative skewness). Barely half of all series are integrated of order one, most series are stationary. Furthermore, only eight series in our data set are negatively skewed (mostly steel alloys). The remaining eleven series (mostly precious and non-ferrous metals) seem to follow a positively skewed distribution. The kurtosis statistic is mostly well in excess of three, indicating a leptokurtic distribution for all metals. Hence, larger price peaks are relatively common among all series.

[Insert Figure 4 here.]

Figure 4 reveals some first insights into the tendency of related metal prices to move together. Thereby, co-movement seems to be especially present in the later part of the sample and within metal groups. Regarding the non-ferrous metals, copper and lead prices follow a very similar trend while tin prices exhibit a more volatile pattern. Precious metal prices seem to to be relatively separated before 1970. But, from 1970 onwards, silver, gold, and platinum prices show very similar movements. The remaining series (steel alloys, light metals and electrical metals) are less correlated at first glance.

4 Econometric analysis

The dynamics of metal prices during the past 100 years are analyzed by investigating co-movement and price cycles both in the short and in the long-run. The econometric analysis of this study is closely related to the work of Cashin et al. (2002) and Roberts (2009) for short-run cycles and Cuddington & Jerrett (2008) for super cycles. Therefore, this section only briefly presents the methodological approach. For additional information, see the literature listed above.

Short term price movements are analyzed by means of short-run cycles that usually vary between two and eight years. Therefore, turning points (peaks and troughs) are defined, and price series are separated into boom and slump phases. Boom phases are characterized by generally rising prices and slump phases by generally falling prices. A shift from a slump (boom) to a boom (slump) phase occurs if prices have risen (fallen) since the last local trough (peak). A local trough in series y_t is defined as $y_t \leq y_{t \leq k}$ and a local peak as $y_t \geq y_{t \geq k}$, where k usually varies between one and five. Accordingly, temporary price increases (decreases) are possible during slump (boom) phases. However, the amplitudes of such movements are limited to some extent. The Bry-Boschan algorithm[3] is applied in order to determine the turning points in all series. At first this algorithm searches for local minima and maxima in a highly smoothed time series in order to find approximate regions of the turning points. Afterwards the smoothing is reduced until local

[3] This algorithm was first implemented by Burns & Mitchell (1946) and is still used by the National Bureau of Economic Research in order to define business cycles in the U.S. Economy. For a detailed description of each step algorithm step, see Bry & Boschan (1971).

peaks and troughs are found in the original time series. This study follows Cashin et al. (2002) and Roberts (2009) and modifies the assumptions of the original business cycle algorithm in order to take into account that commodity prices are being analyzed: (1) A cycle (from peak to peak or from trough to trough) must be at least 24 months long (2) A phase (from peak to trough or from trough to peak) must be at least 12 months long (3) The algorithm is applied to real, not trend-adjusted price series. This nonparametric algorithm has the advantage that no assumption about the underlying data-generating process has to be made. It is a very convenient way to summarize periods of falling and rising prices in a consistent and reproducible way (Roberts 2009) and previously defined turning points are not affected as new observations become available. Using the example of zinc prices, Figure 5 illustrates the dating of turning points via the Bry-Boschan algorithm. The shaded areas denote slump phases (generally decreasing prices) and the unshaded areas denote boom phases (generally increasing prices). The right hand side chart illustrates the durations and amplitudes of such defined boom and slump phases. Once peaks and troughs are defined, a number of basic statistics are calculated: number of cycles (peak-to-peak and trough-to-trough), time spent in slump and boom phases, duration of cycles, slumps and booms (minimum, maximum and mean), and amplitudes of boom and slump phases (minimum, maximum, mean).

[Insert Figure 5 here.]

In addition, the excess index developed by Harding & Pagan (2002) is calculated. This index (E_i) sets the shape of the actual price path ($C_i + 0.5 \cdot A_i$) in relation to a "triangle approximation"(C_{Ti}), where A_i represents the amplitude and D_i the duration of phase i. The term $0.5 \cdot A_i$ removes the bias caused by the approximation of the actual price path by a sum of rectangles. The excess index is then given by:

$$E_i = \frac{C_{Ti} - C_i + 0.5 \cdot A_i}{D_i}. \tag{1}$$

It is divided by duration D_i in order to make phases independent from their duration and hence comparable to each other. Thus, it provides a simple measure for the shape of the cycle. In case of linear growth (constant negative or positive growth), this index is equal to zero. A positive excess index during boom phases indicates growth that is greater than it would be under linear growth. For slump phases, a positive index would imply cumulative loss that is stronger than under linear growth.

Furthermore, the Brain-Shapiro test for exponentiality is used (Brain & Shapiro 1983) in order to test for duration dependence (constant hazard function). The hazard function is the conditional probability of phase i ending at time t, given that it has already achieved duration D_i. The exponential distribution is the only distribution with a constant hazard function. Accordingly, Brain & Shapiro (1983) explicitly test for exponentiality and provide two tests, one against the alternative of monotonic hazard functions (z) and the second one against non-monotonic hazard functions (z*). Under the null hypothesis, the probability of terminating a phase is independent of the period a time series has already spent in that phase (no duration dependence). A negative (positive) Brain-Shapiro statistic indicates positive (negative) duration dependence (Diebold & Rudebusch 1990). Positive duration dependence means that the longer a phase has already lasted the more likely it will end. In contrast, negative duration dependence means that the longer a phase has already lasted the more unlikely it will end (Cashin & McDermott 2002).

Considering short-run price cycles, co-movement is measured by the proportion that two time series $Y_{i,t}$ and $Y_{j,t}$ spent in the same phase (e.g., Roberts 2009 and Harding & Pagan 2002). For this purpose, the following concordance statistic[4] is used:

$$C_{ij} = \frac{1}{T}\{\sum_{t=1}^{T}(S_{i,t} \cdot S_{j,t}) + \sum_{t=1}^{T}(1 - S_{i,t}) \cdot (1 - S_{j,t})\}, \tag{2}$$

where T is the sample size and $S_{i,t}$ a binary time series that is equal to 1 if series $Y_{i,t}$ is in a boom phase and equal to 0 if series $Y_{i,t}$ is in a slump phase. This statistic has the advantage that it is independent of the selected turning points because it is unaffected by the amplitudes (Cashin et al. 1999). It is equal to one if both series $Y_{i,t}$ and $Y_{j,t}$ are in the same phase at any time. To test the statistical significance of this statistic, Harding & Pagan (2006) suggest a simple t-test based on the correlation coefficient (ρ) between series $S_{i,t}$ and $S_{j,t}$. Under the null hypothesis of no concordance, this coefficient is equal to zero. The following regression is used in order to estimate ρ and calculate its heteroscedastic and autocorrelation corrected t-statistic:

$$\frac{S_{i,t}}{\hat{\sigma}_{Si}\hat{\sigma}_{Sj}} = \alpha + \rho\frac{S_{i,t}}{\hat{\sigma}_{Si}\hat{\sigma}_{Sj}} + e_t, \tag{3}$$

where $\hat{\sigma}_{Si}$ and $\hat{\sigma}_{Sj}$ are the estimated standard deviation of $S_{i,t}$ and $S_{j,t}$.

Considering long-run price cycles, the co-movement between two series can also be measured by the degree to which its super cycle components are correlated (Lescaroux 2009). For this purpose, the asymmetric band-pass (BP) filter[5] by Christiano & Fitzgerald (2003) is applied to decompose real (log) metal prices P_t into three cyclical components: the long-run trend, the super cycle component and other (shorter) cyclical components. In general, linear BP filters ($BP_{(P_L,P_U)}$) are applied in order to pass through certain cyclical components within a specific range of duration (P_L, P_U) and filter out higher and lower frequency components. Therefore, two-sided weighted moving averages are used where the corresponding weights are determined by means of spectral analysis. In the case of symmetric BP filters, these weights are constant.

[4] Another way to analyze co-movement would be to test for cointegration. These tests are based on the assumption that two (or more) time series are not stationary and exhibit the same order of integration (e.g., Lütkepohl & Krätzig 2004). Since some series in the data set are integrated of order one and others are stationary (see section 3), these tests are not applied here.

[5] For a detailed description of its advantages and uses, see Erten & Ocampo (2013).

Such filter methods have the benefit that no assumption about the underlying data model has to be made. Moreover, the asymmetric BP filter has the major advantage (in comparison to symmetric filters) that no observations at the beginning or the end of the time series get lost because all weights on leads and lags can differ. Following Cuddington & Jerrett (2008), Jerrett & Cuddington (2008) and Erten & Ocampo (2013), real (log) prices are decomposed as follows:

$$P_t = ST_{(2,20)} + SC_{(20,70)} + LT_{(70,\infty)}, \tag{4}$$

where SC is the super cycle component that varies between 20 and 70 years and LT is the long-run trend that encompasses all cyclical components that last longer than 70 years, Shorter components $ST_{(2,20)}$ are filtered out as cycles between 2 and 20 years. The non-trend component NT is simply the deviation from the long-run trend and is defined as the sum of other shorter cycles and the super cycle:

$$NT = ST_{(2,20)} + SC_{(20,70)}. \tag{5}$$

Figure 6 illustrates the results of the decomposition of time series by means of the asymmetric BP filter using the example of zinc prices. The super cycle component and the non-trend component are displayed in the lower area. Since the scaling of both axes is in logarithms a value of 0.5 for the non-trend component corresponds to a deviation of 50 %. The upper area shows the original real prices series and the overall long-run trend which, in this case, is clearly decreasing.

[Insert Figure 6 here.]

5 Results

5.1 Correlation and concordance analysis

The full sample correlation analysis in table 2 (lower triangle matrix) reveals significant positive correlations. Considering all metal series, the highest correlations are displayed between lead and copper prices (0.847) and between aluminum and magnesium prices (0.826). Regarding the non-ferrous metals, tin prices seem to follow different movements since they exhibit overall lower correlation coefficients, as already suggested by Figure 4. Remarkably, tin prices are closely related to the majority of steel alloy prices. Furthermore, silver prices are strongly correlated both with gold and platinum prices and with copper and lead prices. This is not surprising since silver is not only used by the jewelry industry and traded as an investment asset like gold, but it also has industrial uses like copper and lead. One striking result is, that the correlation between platinum and palladium prices is very low (0.243). The prices of both metals are mainly driven by their industrial uses and their greatest source of demand is the automotive industry where they are processed into autocatalysts. Despite the high degree of substitutability between both metals, their prices do not indicate significant co-movement during the last 100 years. The correlation coefficients among steel alloy prices are rather mixed; ranging from 0.139 between cobalt and chromium prices up to 0.792 between molybdenum and manganese prices. In addition, steel prices are significantly and positively correlated (> 0.5) for all steel alloy prices except cobalt. Even though steel is made out of iron ore, the correlation between both metal price series is rather loose (0.449). This can be explained by the fact that iron ore used to be sold based on contract prices, and such, its prices have not shown considerable variations over the past 100 years. However, the correlation analysis also reveals a number of negative correlation coefficients, but these are either not significant or relatively low. Copper prices seem to exhibit the most negative correlation coefficients, whereby the lowest negative correlation is displayed between magnesium and copper prices (-0.319).

[Insert Table 2 here.]

The drawback of using simple correlation coefficients in the analysis of metal price movement is that it is affected by the amplitude and duration of sharp price peaks. Therefore, the concordance statistic which only considers the duration and timing of different cycle phases and not their amplitudes is also applied. The results of the concordance analysis in Table 2 (upper triangle matrix) indicate that the majority of series spent most of the time in the same cycle phase. Accordingly, metal price series exhibit a reasonably strong degree of co-movement, whereby most metal price pairs spent more than 50 percent of the time in the same phase. The lowest concordance statistic (0.463) is displayed between platinum and manganese prices and the highest (0.791) between lead and zinc prices. Regarding within group co-movement, non-ferrous metals, light metals, electrical metals, iron ore and steel exhibit a high degree of co-movement (> 0.7). Precious metals and steel alloy prices spent less time in the same cycle phase.

[Insert Table 3 here.]

Since some of the full sample results are surprising and due to the fact that during the past 100 years very different trends can be observed during the past 100 years, the sample is split into two equal parts in order to examine whether the extent to which metal prices co-move has changed over time. Therefore, the full sample is divided into two roughly 50-years subsamples, namely, the first subsample from 1910 till 1959 and the second subsample from 1960 till 2011. While the first subsample is mostly characterized by periods of wars and economic crisis, globalization, both oil crises and the dramatic increase of international trade dominated the development in the second part of the century. Thus, significant differences with respect to both subsamples are expected.[6] The correlation analysis in Table 3 indicates that the correlation coefficient considerably vary over time. While most correlation coefficients are significantly negative in the

[6] The results of the concordance analysis are not listed here because they do not significantly vary over time.

first subsample, the later part of the sample mostly displays positive correlation coefficients. In general, pairs of metal prices that exhibit a high degree of correlation during the first part of the century are rather loosely correlated during the second part. Some interesting individual results will be briefly presented. While copper and zinc prices hardly co-move (0.181) in the first part of the century, their correlation coefficient rises to 0.667 in the second part and thus indicates a reasonably strong amount of co-movement. The highest correlation in the first subsample is displayed between gold and palladium prices (both precious metals) and between magnesium and aluminum prices (both light metals). Furthermore, the correlation coefficient between steel and iron ore prices is much higher during the first subsample. Accordingly, iron ore and steel markets became more separated over time. While gold prices are negatively correlated with platinum and silver prices during the first subsample, the correlation coefficient switches to (strongly) positive during the second subsample. The same is more or less true for non-ferrous metal prices and steel alloy prices. In addition, the correlation between steel alloy prices and the steel price is much stronger in the second subsample between 1960 and 2011.

To sum up, the degree of correlation is not particularly high for the full sample but significantly varies over time. While correlation coefficients in the first subsample mostly exhibit negative values, the later part of the sample displays positive correlation coefficients. Evidence of co-movement can be mainly found for the second subsample where correlation coefficients are generally higher. These findings confirm the results in the literature (e.g., Vansteenkiste 2009) that metal prices became more synchronized over time. The only exceptions are iron ore and steel prices. Similar to the results in Roberts (2009), the concordance statistic indicates a strong overall amount of co-movement regarding the duration and timing of short-run cycle phases. Accordingly, the results of this study partly contradict the findings of Cashin et al. (1999) who do not find a high proportion of co-movement (between agricultural and mineral commodities) based on their concordance analysis. Furthermore, they conclude that co-movement is not a general phenomenon, but that related commodities like metals (aluminum, copper, gold, lead, tin and zinc) do move together. Based on the analysis in this study, this is a conclusion that can not only be drawn for commodities in general, but also for metals: metal price co-movement is not a general characteristic among metal prices, it rather is a phenomenon that is valid within specific groups of metals but not between them.

5.2 Short-run price cycles

Averaging across all metals, the time spent in slump phases is 63.72 % (see table 4) and, therefore, higher than the average time spent in boom phases (36.28 %). Magnesium, chromium, molybdenum, iron ore and bismuth prices spent almost three quarters of the time in slump phases. Regarding the groups of metals, the time spent in slump phases varies between 58.19 % for non-ferrous metals and 70.68 % for electrical metals. Thereby, the highest degree of variation is noticeable within the group of steel alloys. While cobalt prices only spent 58.44 % of the time in slump phases, the figure for molybdenum prices was 72.35 %. As for the full sample correlation analysis, the results for iron ore and steel prices differ considerably. While iron ore prices spent 73.09 % of the time in slump phases, steel only spent 58.09 % there.

[Insert Table 4 here.]

The total number of cycles (peak-to-peak/trough-to-trough) varies between 10/10.5 for electrical metal prices and 17/16.75 for non-ferrous metal prices. Regarding individual time series, the number of cycles varies between 18/19 for lead prices and 7/7 for iron ore prices. Nevertheless, these values cannot be compared directly because several price series are not available for the whole time period. With respect to those time series that are available from 1910 onwards, the number of cycles ranges from 10/10 for gold prices up to 18/19 for lead prices. Table 4 also list the number of cycles for a smaller subsample; the one that is available for all prices series (1936M01 - 2011M12). Again, non-ferrous metals exhibit the most (12.5/12) and iron ore and steel the least number of cycles (7.5/7). The average cycle of all metals exhibits 9.8/9.55 months. Regarding the precious metals, gold and palladium prices are characterized by an above-average number of cycles (10/11) and silver and palladium prices by a below-average number of cycles (7/8). Averaging across all metal series, the length of a complete cycle varies between 36.70 and 178.65 months. Consistent with the finding that non-ferrous metal prices exhibit the most number of completed cycles, their average duration of price cycles is relatively short (67.97 months).

The results of the excess index indicate that growth during boom phases is usually greater than someone would expect under linear growth. Nevertheless, considering all price series simultaneously, the excess index is equal to zero indicating an overall linear growth during boom phases. With the exception of steel alloy and platinum prices, the excess index during slump phases is positive. Accordingly, the cumulative loss during slump phases is greater than it would be under linear negative growth. Contrary to the results in Davutyan & Roberts (1994), the results of the Brain-Shapiro test reveal no significant duration dependence for the majority of metal prices. Copper, tin, gold and aluminum prices are the only exception. Davutyan & Roberts (1994) analyzed annual metal prices (lead, zinc, mercury, tin and copper) between 1850 and 1991 and found weak evidence of positive duration dependence. However, Cashin et al. (2002) considered, among other commodities, gold, aluminum, copper, iron ore, lead, nickel, tin and zinc monthly prices between 1957 and 1999 and did not find any evidence of duration dependence. Furthermore, there is no significant correlation between the amplitude and the duration of phases (as in Roberts 2009). This is true for both slump phases and boom phases.

Next, boom and slump phases are considered separately (see Tables 6 and 5). Figure 1 shows the average duration of boom and slump phases for all 20 metals. For each metal, the average duration of slump phases is longer than the average duration of boom phases. Averaging across all metals, slump phases last 53.97 months and boom phases 33.33 months. Furthermore, as also indicated by Figures 2 and 3, slump phases exhibit more variation regarding their average duration. Figure 2 and 3 display the distribution of the duration of boom and slump phases. Remember that both figures are censored at the bottom due to the restriction that a phase must be at least 12 months long. The findings are very similar to the results of Roberts (2009): The duration of boom phases varies between 15 and 35 months and just a few boom phases last longer than 55 months. Furthermore, the distribution is positively skewed. In comparison, the average duration of slump phases is more broadly distributed, that is between 12 and 85 months with many slump phases lasting longer than 55 months. On average, slump phases of iron ore and steel are almost twice as long as non-ferrous metals slump phases.

[Insert Figure 1, 2, 3 and here.]

The most dramatic price fall (-298.91 %) is visible between January 1980 and March 1993 (159 months) for silver prices. After the Hunt brothers attempt to corner the silver market, the speculation bubble burst in 1980 and demand from the investment sector collapsed such that prices fell dramatically. On the other hand, the most dramatic price increase varies between 245.87 % for cobalt prices during the time between December 1969 and January 1979 (110 months) and 121.84 % for steel prices between December 1914 and July 1917 (32 months). Cobalt prices increased sharply in response to the invasion of several cobalt mines in Zaire. At the same time, worldwide demand was high and the US government ended its stock sales such that concerns regarding future supply put upward pressure on prices. Strong demand for ammunitions during the First World War triggered rising steel prices. The strongest price increase during the shortest period of time (205.76 % in 21 months) occurred between July 1914 and March 1916 for antimony prices. This drastic increase was driven by strong demand during the First World War where antimony was heavily used in the production of ammunition. Averaging across all metals, the strongest price increases are less pronounced (in absolute terms) but shorter (177.19 % in 51.85 months) than the strongest price falls (-191.71 % in 84.20 months). Accordingly, metal prices increase more strongly in a shorter period of time than they fall. Considering the groups of metals, steel alloy prices exhibit the most dramatic price movements and iron ore and steel prices are characterized by smaller price peaks which gradually develop over a longer period of time.

[Insert Table 5 and 6 here.]

Summing up, the average time spent in slump phases is longer than the average time spent in boom phases. Furthermore, confirming the results of Cashin et al. (2002) and Roberts (2009), short-run cycles in metal prices are asymmetric. The average duration of slump phases is significantly longer than the average duration of boom phases. The distribution of the duration of boom phases is positively skewed while the duration of slump phases is more broadly distributed. The number of cycles (peak-to-peak/trough-to-trough) significantly varies depending on the specific metal under consideration and ranges from 18/19 for lead prices, to 7/7 for iron ore prices. Overall, non-ferrous metal prices exhibit the most number of completed cycles and steel and iron ore prices the least. Regarding the amplitude and the duration of cycle phases, no general duration dependence can be found. Hence, the probability of a phase ending at time t is independent of the duration that a time series has already spent in this phase. Additionally, the duration and the amplitude of phases are not significantly correlated. The excess index indicates that growth both during boom and during slump phases is usually greater than it would be expected under simple linear growth. The findings with respect to the excess index, duration dependence and the correlation between the duration and amplitude of slump and boom phases is very similar for all metals and correspond to the results in the literature.

5.3 Long-run trend

Similar to the results of Cuddington & Jerrett (2008) and Jerrett & Cuddington (2008), the majority of metal price series can be characterized by four super cycles during the last 100 years. While three metal price series (aluminum, cobalt, steel) exhibit five super cycles, four series (nickel, molybdenum, palladium, silver) only show three cycles. Bear in mind that not all series are available for the whole time period. Therefore, it may not be surprising that nickel, molybdenum and palladium exhibit a lower number of super cycles than the majority of metals. Nevertheless, silver prices are available from 1910 onwards, yet, its number of super cycles (3) is below average (4). A closer look at silver prices reveals that its super cycle component was relatively stable between May 1932 and December 1965. In contrast, the long-run price cycles of aluminum, cobalt and steel differ significantly. While aluminum prices display five super cycles with reasonably strong amplitudes during both boom and slump phases, the super cycle components of cobalt and steel prices are less pronounced.

All the same, the majority of metal prices confirm the findings in the literature. Metal prices are characterized by four super cycles during the following periods of time: before 1910-1938 (peak: 1923), 1938-1968 (peak: 1953), 1968-1996 (peak: 1985), 1996-ongoing (peak: ?). Aluminum, cobalt and steel prices exhibit one additional super cycle between 1958 and 1995: 1958-1980 (peak: 1972) and 1980-1995 (peak: 1989). The dynamics of nickel, molybdenum, palladium and silver prices follow three larger super cycles: before 1910-1953 (peak: 1934), 1953-1993 (peak: 1978) and 1993-ongoing (peak: ?).

The correlation matrix in Table 7 displays significant positive correlations between the super cycle components of all metal prices. The only exception is cobalt; its prices are significantly negatively correlated with steel alloy prices. However, these correlations are relatively small. With regard to non-ferrous metals, the correlation of super cycle components is strong (> 0.7). Furthermore, with the exception of silver and platinum prices (0.761) and gold and silver prices (0.685), the super cycle components of precious metals seem to be less correlated (< 0.5). Again, platinum and palladium prices are barely correlated (0.012). Among the steel alloys, several pairs of super cycle components are strongly correlated (for example, molybdenum and manganese (0.724) and nickel and molybdenum (0.856)). Apart from this, steel alloy prices are characterized by relatively distinct super cycle components. The super cycle components between both light metals and between steel and iron ore prices are strongly correlated (~ 0.75). Thus, co-movement of steel and iron ore prices cannot be found in the short-run (see section 5.2) but in the long-run. Antimony and bismuth super cycle components show less correlation (0.534). Considering all metal price series, precious and non-ferrous metals are strongly correlated.

[Insert Table 7 here.]

Again, the full sample is divided into two equal parts in order to investigate the changing behavior of co-movement over time (see Table 8). Just as for the simple correlation analysis, the first subsample (1910-1959) mostly reveals significantly negative correlation coefficients whereas the second subsample (1960-2011) shows positive and overall stronger correlation coefficients. An exception are non-ferrous metals, their super cycles components are strongly positively correlated both during the first and during the second part of the century. While the super cycle components of palladium and gold prices are positively correlated only in the first subsample, silver and platinum super cycle components are strongly positively correlated in both subsamples. The remaining pairs of precious metals switch from negative to positive correlation coefficients. Super cycle components of tungsten prices and the other steel alloy prices are uniformly negatively correlated in the first subsample and positively correlated in the second subsample.

[Insert Table 8 here.]

Table 9 lists a number of descriptive statistics regarding the super cycle components of all metal series. As mentioned above, the majority of metals have exhibited four super cycles during the last 100 years. The average duration of a super cycle is 362 months ($\sim$ 30 years) and varies between 201 months ($\sim$ 17 years) for steel prices (1929 M08-1946 M06, peak 1946 M06) and 555 months ($\sim$ 46 years) for nickel prices (1949 M10-1995 M11, peak: 1978 M03). The average boom phase lasts 185 months and the average slump phase 183 months. Thereby, the duration of boom phases and slump phases show a similar strong variation: boom phases last between 72 months (magnesium) and 340 months (magnesium) and slump phases between 63 months (steel) and 342 months (nickel). Regarding the groups of metals, the average duration of the super cycles does not significantly vary. While super cycle components of light metals last 318 months (on average), the super cycle components of precious metals are 396 months long. The only exceptions are iron ore and steel prices.

[Insert Table 9 here.]

The most dramatic price decrease (-156.26 %) is visible for molybdenum prices during the time period between 1975M04 and 1992M11. Molybdenum prices also exhibit the most drastic price increase: between

1991M11 and 2008M10 prices increased by 168.40 %. Averaging across all metals, price increases (53.30 %) are approximately as strong as prices falls (-57.78 %). Nevertheless, price movements seem to be less pronounced for light metals (-34.46 %, + 31.67 %) and the most pronounced for precious metals (-73.45 %, +66.05 %).

Finally, table 10 lists a number of descriptive statistics regarding the long-run behavior of metal prices. Similarly to the results of Cuddington & Nülle (2014), commodity prices exhibit a wide variety of long-run trends over the past 100 years: aluminum prices monotonically decrease (-154.52 %) over the entire time period. The long-run trends of tin and zinc prices switch from negative to positive in 1926/1946 and again to negative in 1970/1979. Contrary to Cuddington & Nülle (2014), the long-run trend of nickel prices does not change over time, rather it gradually increases (39.25 %) between 1929 and 2011. Furthermore, the long-run prices of copper and lead increase between 1920 and 2011. The average deviation from the long-run trend is relatively small and varies between -4.73 % for tungsten prices and 3.95 % for palladium prices. Nevertheless, this deviation can be quite large during certain periods of time: it ranges from -187.18 % for tungsten prices up to 185.56 % for iron ore prices. More than half of all price series exhibited an overall constant long-run trend over the past 100 years. Thereby, six price series decreased and five series increased over the whole period of time. The strongest price increase is visible for copper prices (133.28 % between 1910 and 2011) and the strongest price fall for molybdenum prices (-169.84 % between 1934 and 2011). The remaining metal series are characterized by both decreasing and increasing periods of time.

[Insert Table 10 here.]

Overall, the results for the majority of metal price series confirm the results in the literature and can be characterized by four super cycles during the last 100 years: 1910-1938 (peak: 1923), 1938-1968 (peak: 1953), 1968-1996 (peak: 1985), 1996-ongoing (peak: 2010). Just as for the simple correlation analysis, the first subsample (1910-1959) mostly reveals significantly negative correlation coefficients and the second subsample (1960-2011) positive and overall stronger correlation coefficients. Accordingly, metal prices became more synchronized over time. The only exception are non-ferrous metals; their super cycles components are strongly positively correlated both during the first and during the second part of the century. Boom and slump phases take roughly the same span (185/183 months) and show similar strong variation over the full period of time. However, the long-run component of metal prices considerably varies amongst the set of metal prices: multiple changes in the sign of the long-run component are usual. Nevertheless, the majority of prices series exhibit a monotonically decreasing trend during the past 100 years.

6 Summary

This paper explores the dynamics of a number of mineral commodities during the past 100 years. Most series span the period between January 1910 and December 2011, giving a total of 1224 monthly observations. Based on a unique data set, this study analyzes co-movement, cycles and long-run trends by means of common statistical methods. The results for five different groups of metal prices (non-ferrous metals, precious metals, steel alloys, light metals, electrical metals, iron ore and steel) are compared to the findings in the literature. Compared to earlier studies, this analysis has the major advantage that a large number of monthly observations (1224) over a wide variety of metals (20) is being considered. This data length is a huge asset in comparison to previous studies which are mostly restricted to the history of the recent 50-60 years or are based on yearly data frequency.

Findings in this study suggest that commonly assumed characteristics of metal prices are not necessarily valid for this wider set of mineral commodities. This is especially true regarding co-movement and short-run price cycles of metals. As indicated by the correlation and concordance analysis, metal prices became more synchronized over time. The only exceptions are iron ore and steel, whose prices became more separated over time. The degree of correlation in the first subsample (1910-1959) is mostly negative and switches to positive in the second subsample. Furthermore, co-movement is not a general characteristic among metal prices, it is rather a phenomenon that is valid within specific groups of metals but not necessarily between them, as indicated by correlations coefficients that are stronger within groups than between them. The number of cycles significantly varies depending on the specific metal under consideration. Overall, non-ferrous metal prices exhibit the largest number of completed cycles. The highest degree of variation is noticeable within the group of steel alloys. Finally, the long-run component of metal prices considerably varies over the set of metal prices: multiple changes in the sign of the long-run component are not unusual.

Nevertheless, a number of findings are valid for the entire data set: Price cycles are asymmetric. The average time spent in slump phases is longer than the average time spent in boom phases and, on average, slump phases last significantly longer than boom phases. Furthermore, metal prices increase more strongly in a shorter period of time than they fall. No significant evidence of duration dependence can be found. The probability of a phase ending is independent of the duration that a time series already spent in this phase. In addition, there is no significant correlation between the amplitude and the duration of phases. The majority of metal price series confirm the results in the literature and can be characterized by four super cycles during the last 100 years: 1910-1938 (peak: 1923), 1938-1968 (peak: 1953), 1968-1996 (peak: 1985), 1996-ongoing (peak: ?). Boom and slump phases in super cycles take, on average, roughly the same length of time (185/183 months) and show similarly strong variation.

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A Appendix

Table A.1: Data description and sources

series	description	sources
aluminum	1910-1959: New York, no. 1 virgin, min. 98-99 %; 1960-1968: London Metal Exchange, high grade, min. 99.7 %; 1969: unalloyed ingot; 1970-2011: London Metal Exchange, high grade, min. 99.7 %	1910-1959: American Metal Market; 1960-1968: Federal Institute for Geosciences and Natural Resources; 1969: Engineering and Mining Journal; 1970-2011: Federal Institute for Geosciences and Natural Resources
antimony	1910-1978: Chinese and Japanese (ordinary brands), New York; 1979-2011: Antimony Regulus, 99.65 %	1910-1978: American Metal Market; 1979-2011: Federal Institute for Geoscience and Natural Resources
bismuth	1934-1950: New York, lots; 1951-1961: New York, lots, 97/99 %; 1962-1978: New York, ton lots; 1979-2011: European Warehouse, 99.99 %	1934-1950: Engineering and Mining Journal; 1951-1961: Metallgesellschaft AG; 1962-1978: Engineering and Mining Journal; 1979-2011: Federal Institute for Geosciences and Natural Resources
chromium	1934-1948: New York, ferro, 65-70 %; 1949-1961: New York, ferro, 65-69 %; 1962-1974: New York, ferro, 67-73 %; 1975-1978: New York, ferro, 67-71 %; 1979-2011: frei Verbraucher, ferro, 60 %	1934-1978: Engineering and Mining Journal; 1979-2011: Federal Institute for Geosciences and Natural Resources
cobalt	1936-1962: New York, 97/99 %; 1963-1966: New York, 99 %, lots; 1967-2011: MB Freimarkt, min. 99.8 %	1936-1950: Engineering and Mining Journal; 1951-1962: Metallgesellschaft AG; 1963-1966: Engineering and Mining Journal; 1967-2011: Federal Institute for Geosciences and Natural Resources
copper	1910-1927: New York, casting copper; 1928-1959: United States, electrolytic copper; 1960-2011: London Metal Exchange, grade A	1910-1927: American Metal Market; 1928-1959: U.S. Geological Survey; 1960-2011: Federal Institute for Geosciences and Natural Resources
gold	1910-1937: London; 1938-1949: prices fixed; 1950-1969: London; 1970-1978: US monthly selling prices; 1979-2011: London, 99.9 %	1910-1931: Warren et al. (1932); 1932-1937: American Metal Market; 1938-1949: prices fixed; 1950-1969: Deutsche Bundesbank; 1970-1978: U.S. Geological Survey; 1979-2011: Federal Institute for Geosciences and Natural Resources
iron ore	1929-1959: Messabi bessemer, Lake superior; 1960-2010: Europe, CVRD Feinerz, 64.5 %; 2010-2011: Feinerz, spot market, 63.5 %	1929-1934: U.S. Geological Survey; 1934-1959: Engineering and Mining Journal; 1960-2011: Federal Institute for Geosciences and Natural Resources
lead	1910-1929: New York, pig lead; 1930-1960: New York; 1961-2011: London Metal Exchange, min. 99.97 %	1910-1929: American Metal Market; 1930-1960: U.S. Geological Survey; 1961-2011: Federal Institute for Geosciences and Natural Resources
magnesium	1934-1962: New York, 99.8 %, notched ingot; 1963-1965: fob ship. pt. pig ingot, 99.8 %; 1966-1978: fob Texas, 99.8 %; 1979-2011: MB Freimarkt, min. 99.8 %	1934-1950: Engineering and Mining Journal; 1951-1962: Metallgesellschaft AG; 1963-1965: Engineering and Mining Journal; 1966-2011: Federal Institute for Geosciences and Natural Resources

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manganese	1910-1964: fob Baltimore, ferro, 78-82 %; 1965-1978: New York, ferro, 74-78 %; 1979-2011: frei Verbraucher, ferro, 78 %	1910-1964: American Metal Market; 1965-1978: Engineering and Mining Journal; 1979-2011: Federal Institute for Geosciences and Natural Resources
molybdenum	1934-1937: New York, ferro, 50-60 %; 1938-1955: New York, ferro, 55-65 %; 1956-1978: fob shipping point, ferro, 58-64 %; 1979-2011: frei Verbraucher, ferro, 65-70 %	1934-1978: Engineering and Mining Journal; 1979-2011: Federal Institute for Geosciences and Natural Resources
nickel	1929-1959: fob Port Colborne, cathodes; 1960-1970: London Metal Exchange, cathodes, min. 99.8 %; 1971-1979: LME; 1980-2011: London Metal Exchange, primary Nickel, min. 99.8 %	1929-1959: Engineering and Mining Journal; 1960-1970: World Bank; 1971-1979: Qiang & Weber (1995), Qiang (1998); 1980-2011: Federal Institute for Geosciences and Natural Resources
palladium	1931-1967: New York; 1968-1977: historical London fix prices; 1978-1985: New York, dealer price; 1986-2011: London, 99.95 %	1931-1934: U.S. Geological Survey; 1935-1967: Engineering and Mining Journal; 1968-1977: www.kitco.com; 1978-1985: U.S. Geological Survey; 1986-2011: Federal Institute for Geosciences and Natural Resources
platinum	1910-1978: New York; 1979-2011: London, 99.95 %	1910-1978: American Metal Market; 1979-2011: Federal Institute for Geosciences and Natural Resources
silver	1910-1978: New York, London; 1979-2011: London, 99.5 %	1910-1978: American Metal Market; 1979-2011: Federal Institute for Geosciences and Natural Resources
steel	1910-1978: Pittsburgh, steel bars; 1979-1989: World, steel rebar; 1990-2011: European, merchandise rebar	1910-1978: Metal statistics; 1979-1989: World Bank; 1990-2011: Federal Institute for Geosciences and Natural Resources
tin	1910-1971: New York, straits tin; 1972-1978: London Metal Exchange, standard tin; 1979-2011: London Metal Exchange, min 99.85 %	1910-1971: American Metal Market; 1972-1978: Qiang 1995, Qiang 1998; 1979-2011: Federal Institute for Geosciences and Natural Resources
tungsten	1917-1964: wolframite, ordinary quality; 1965-1977: cif US ports, 65 %; 1978-2011: concentrate, min. 65 %	1917-1964: American Metal Market; 1965-1977: U.S. Geological Survey; 1978-2011: Federal Institute for Geosciences and Natural Resources
zinc	1910-1930: East St. Louis, prime western zinc; 1931-1970: East St. Louis, common metallic zinc; 1971-1978: London Metal Exchange, common metallic zinc; 1979-2011: London Metal Exchange, special high grade, min. 99.95 %	1910-1930: American Metal Market; 1931-1978: U.S. Geological Survey; 1979-2011: Federal Institute for Geosciences and Natural Resources

Table 1: Descriptive statistics log metal prices

	start date	obs.	mean	std. dev.	min.	max.	skew.	kurt.	Jarque-Bera	ADF (level)	ADF (first dif.)	ARCH	AR(1)
non-ferrous metals													
copper	1910:01	1224	7.761	0.595	6.384	9.561	0.340	2.506	36.043	0.254	-20.721	3.638	0.993
									(0.00)	(0.76)	(0.00)	(0.06)	(0.00)
lead	1910:01	1224	0.653	0.521	5.623	8.365	1.008	3.649	228.856	-2.650	-21.603	12.921	0.990
									(0.00)	(0.08)	(0.00)	(0.00)	(0.00)
tin	1910:01	1224	9.656	0.469	8.446	10.889	-0.043	2.977	0.405	-0.052	-22.384	139.813	0.992
									(0.82)	(0.67)	(0.00)	(0.00)	(0.00)
zinc	1910:01	1224	7.569	0.361	6.670	9.276	1.100	6.044	719.494	-4.322	-20.467	110.700	0.985
									(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
precious metals													
gold	1910:01	1224	6.229	0.404	55.57	7.575	0.643	2.884	85.206	0.608	-23.143	84.391	0.992
									(0.00)	(0.85)	(0.00)	(0.00)	(0.00)
palladium	1931:01	972	5.602	0.397	4.831	7.198	0.793	3.803	127.989	-2.979	-18.901	70.471	0.985
									(0.00)	(0.04)	(0.00)	(0.00)	(0.00)
platinum	1910:01	1224	6.810	0.370	6.006	7.831	0.571	2.711	70.931	-3.269	-23.135	47.064	0.986
									(0.00)	(0.02)	(0.00)	(0.00)	(0.00)
silver	1910:01	1224	2.252	0.469	1.337	4.731	1.175	5.004	487.00	-0.123	-19.087	127.582	0.989
									(0.00)	(0.64)	(0.00)	(0.00)	(0.00)
steel alloys													
chromium	1934:04	933	7.633	0.324	6.692	8.791	-0.023	4.346	70.570	-3.725	-13.790	134.780	0.986
									(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
cobalt	1936:01	912	10.735	0.449	9.767	12.587	1.181	5.193	395.066	-3.237	-19.087	2.820	0.983
									(0.00)	(0.02)	(0.00)	(0.09)	(0.00)
manganese	1910:01	1224	7.287	0.469	6.178	9.049	-0.057	3.457	11.377	-3.368	-14.091	0.832	0.991
									(0.00)	(0.01)	(0.00)	(0.36)	(0.00)
molybdenum	1934:04	933	10.735	0.778	9.014	12.335	-0.864	2.279	136.310	-0.499	-18.611	17.732	0.995
									(0.00)	(0.50)	(0.00)	(0.00)	(0.00)
nickel	1929:01	996	9.427	0.338	8.577	10.940	0.885	4.884	277.665	-3.556	-18.752	15.905	0.985
									(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
tungsten	1917:01	1140	5.217	0.688	3.334	6.590	-0.301	2.185	48.810	-0.593	-19.701	36.366	0.994
									(0.00)	(0.46)	(0.00)	(0.00)	(0.00)
light metals													
aluminum	1910:01	1224	8.269	0.518	7.251	10.087	0.766	3.896	160.990	-4.756	-13.762	102.286	0.995
									(0.00)	(0.00)	(0.28)	(0.00)	(0.00)
magnesium	1934:04	933	8.744	0.500	7.512	9.626	-0.547	2.766	48.741	-1.020	-9.244	9.590	0.995
									(0.00)	(0.28)	(0.00)	(0.00)	(0.00)
electrical metals													
antimony	1910:01	1224	8.255	0.570	6.788	9.715	0.072	3.009	1.091	-3.095	-19.820	33.428	0.989
									(0.58)	(0.03)	(0.00)	(0.00)	(0.00)
bismuth	1934:04	933	9.988	0.554	8.825	11.237	-0.398	2.121	54.677	-0.252	-18.552	6.778	0.993
									(0.00)	(0.60)	(0.00)	(0.01)	(0.00)
steel and iron ore													
iron ore	1929:01	996	3.937	0.448	3.106	5.294	-0.122	2.445	15.212	0.501	-22.403	0.101	0.992
									(0.00)	(0.82)	(0.00)	(0.75)	(0.00)
steel	1910:01	1224	6.135	0.327	5.413	7.153	0.163	2.063	50.203	-2.644	-22.357	24.508	0.992
									(0.00)	(0.08)	(0.00)	(0.00)	(0.00)

Note: Log metal prices, obs. = number of observations, std.dev. = standard deviation, min. = minimun, max. = maximum, skew. = skewness, kurt. = kurtosis; Jarque-Bera = Jarque-Bera test statistic for normality, ADF = Augmented Dickey Fuller test statistic for stationarity (number of lags and deterministic terms are chosen via BIC), ARCH = Lagrange Multiplier test statistic for the presence of ARCH in the residuals, AR(1) = estimated first order autoregression coefficients; *p*-values in parenthesis.

Table 2: Correlation and concordance analysis of (log) metal prices - full sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) copper		0.750	0.764	0.739	0.641	0.638	0.752	0.672	0.667	0.559	0.610	0.613	0.675	0.690	0.682	0.593	0.673	0.706	0.628	0.668
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(2) lead	0.847		0.746	0.791	0.587	0.611	0.697	0.639	0.556	0.577	0.577	0.587	0.601	0.650	0.645	0.556	0.691	0.678	0.628	0.582
	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.14)	(0.00)	(0.00)	(0.00)	(0.00)
(3) tin	0.302	0.464		0.725	0.606	0.643	0.650	0.716	0.587	0.632	0.550	0.674	0.625	0.674	0.691	0.630	0.730	0.678	0.589	0.688
	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(4) zinc	0.404	0.500	0.505		0.604	0.654	0.655	0.614	0.609	0.626	0.617	0.605	0.633	0.632	0.729	0.583	0.683	0.747	0.603	0.596
	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(5) gold	0.512	0.651	0.326	0.285		0.675	0.670	0.744	0.666	0.703	0.547	0.724	0.661	0.623	0.771	0.684	0.628	0.703	0.654	0.616
	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(1.00)	(0.00)	(0.64)	(0.00)	(0.00)	(0.00)	(1.00)	(1.00)	(0.00)	(1.00)	(1.00)	(0.00)
(6) palladium	0.151	0.167	-0.036	0.097	0.375		0.614	0.590	0.594	0.648	0.538	0.636	0.630	0.682	0.720	0.610	0.545	0.641	0.542	0.559
	(0.00)	(0.00)	(0.28)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.36)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.61)	(0.00)	(0.80)	(0.00)
(7) platinum	0.606	0.660	0.461	0.361	0.446	0.279		0.648	0.550	0.546	0.463	0.584	0.594	0.635	0.599	0.554	0.643	0.607	0.571	0.514
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.51)
(8) silver	0.737	0.775	0.673	0.351	0.663	0.243	0.683		0.605	0.558	0.657	0.686	0.630	0.572	0.661	0.651	0.736	0.648	0.649	0.638
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.04)	(0.00)	(1.00)	(0.00)	(0.30)	(0.00)	(1.00)	(1.00)	(1.00)	(1.00)	(0.00)
(9) chromium	0.496	0.530	0.647	0.518	0.350	-0.239	0.494	0.535		0.616	0.700	0.659	0.675	0.578	0.649	0.725	0.662	0.732	0.723	0.650
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(1.00)	(1.00)	(0.00)	(1.00)	(0.00)	(1.00)	(1.00)	(1.00)	(1.00)	(0.00)
(10) cobalt	0.318	0.482	0.102	0.091	0.481	0.139	0.134	0.284	0.139		0.531	0.600	0.645	0.576	0.691	0.701	0.529	0.682	0.595	0.650
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.58)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.70)	(0.00)	(0.00)	(0.00)
(11) manganese	-0.239	-0.018	0.507	0.333	-0.051	-0.211	0.175	-0.017	0.474	-0.060		0.563	0.559	0.543	0.577	0.630	0.616	0.684	0.766	0.698
	(0.00)	(0.60)	(0.00)	(0.00)	(0.13)	(0.00)	(0.00)	(0.61)	(0.00)	(0.07)		(0.69)	(0.01)	(0.69)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(12) molybdenum	-0.127	0.019	0.602	0.341	-0.101	-0.086	0.277	0.122	0.349	-0.063	0.792		0.679	0.658	0.725	0.754	0.679	0.657	0.680	0.636
	(0.00)	(0.57)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.06)	(0.00)		(0.00)	(1.00)	(1.00)	(0.00)	(1.00)	(1.00)	(1.00)	(0.00)
(13) nickel	0.686	0.577	0.356	0.476	0.387	0.127	0.598	0.526	0.616	0.171	0.167	0.302		0.668	0.717	0.747	0.662	0.678	0.644	0.628
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(14) tungsten	-0.096	0.142	0.696	0.454	0.132	0.020	0.234	0.219	0.354	0.069	0.643	0.742	0.150		0.646	0.603	0.666	0.677	0.581	0.568
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.55)	(0.00)	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)	(0.00)		(0.00)	(1.00)	(1.00)	(1.00)	(1.00)	(0.01)
(15) aluminum	-0.197	-0.120	0.530	0.320	0.040	0.028	0.124	0.078	0.335	-0.049	0.625	0.711	0.249	0.624		0.701	0.605	0.678	0.644	0.714
	(0.00)	(0.00)	(0.00)	(0.00)	(0.22)	(0.40)	(0.00)	(0.02)	(0.00)	(0.14)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(16) magnesium	-0.319	-0.169	0.591	0.198	0.069	-0.190	-0.116	0.044	0.378	-0.015	0.631	0.568	-0.033	0.641	0.826		0.674	0.694	0.750	0.675
	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)	(0.18)	(0.00)	(0.64)	(0.00)	(0.00)	(0.32)	(0.00)	(0.00)		(1.00)	(1.00)	(1.00)	(0.00)
(17) antimony	0.568	0.654	0.751	0.476	0.380	-0.029	0.594	0.708	0.641	0.148	0.299	0.450	0.501	0.508	0.219	0.225		0.746	0.709	0.613
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.39)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(1.00)	(0.00)
(18) bismuth	-0.098	-0.054	0.531	0.451	-0.236	-0.045	0.145	0.035	0.441	-0.315	0.659	0.720	0.240	0.661	0.597	0.547	0.445		0.782	0.633
	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.17)	(0.00)	(0.29)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(1.00)	(0.00)
(19) iron ore	-0.172	-0.023	0.458	0.233	0.044	-0.080	0.295	0.078	0.338	-0.164	0.791	0.681	0.152	0.515	0.493	0.455	0.324	0.560		0.728
	(0.00)	(0.49)	(0.00)	(0.00)	(0.18)	(0.02)	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(1.00)
(20) steel	0.484	0.440	0.660	0.389	0.055	-0.228	0.539	0.524	0.681	0.058	0.506	0.602	0.627	0.316	0.365	0.260	0.641	0.460	0.449	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)	(0.08)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	

Note: Lower triangle matrix: Pearson correlation, p-values in parenthesis; upper triangle matrix: concordance statistic. To test the statistical significance of this statistic, a simple t-test based on the correlation coefficient (ρ) between series $S_{i,t}$ and $S_{j,t}$ is calculated. The binary time series $S_{i,t}$ is equal to 0 if time series $Y_{i,t}$ is in a slump phase and equal to 1 if time series $Y_{i,t}$ is in a boom phase. Under the null hypothesis of no concordance ρ should be equal to zero. The following regression is used in order to estimate ρ and calculate its heteroscedastic and autocorrelation corrected t-statistic: $\frac{S_{i,t}}{\hat{\sigma}_{Si}\hat{\sigma}_{Sj}} = \alpha + \rho\frac{S_{i,t}}{\hat{\sigma}_{Si}\hat{\sigma}_{Sj}} + e_t$, see Harding & Pagan (2006).

Table 3: Correlation analysis of (log) metal prices - subsamples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) copper		0.880	0.413	0.667	0.713	0.264	0.664	0.660	0.555	0.427	0.295	0.253	0.692	0.438	0.219	0.029	0.615	0.200	0.281	0.411
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.47)	(0.00)	(0.00)	(0.00)	(0.00)
(2) lead	0.610		0.500	0.567	0.811	0.262	0.646	0.746	0.530	0.562	0.339	0.259	0.597	0.468	0.200	0.123	0.614	0.088	0.257	0.400
	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)
(3) tin	0.393	0.647		0.512	0.380	-0.023	0.476	0.783	0.669	0.108	0.674	0.684	0.409	0.852	0.709	0.762	0.772	0.573	0.557	0.748
	(0.00)	(0.00)		(0.00)	(0.00)	(0.56)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(4) zinc	0.181	0.621	0.572		0.380	0.140	0.394	0.470	0.578	0.107	0.427	0.400	0.652	0.492	0.524	0.313	0.493	0.487	0.302	0.532
	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(5) gold	-0.660	-0.694	-0.293	-0.222		0.251	0.591	0.765	0.460	0.484	0.122	-0.060	0.375	0.216	0.005	0.066	0.475	-0.190	0.210	0.149
	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.13)	(0.00)	(0.00)	(0.89)	(0.10)	(0.00)	(0.00)	(0.00)	(0.00)
(6) palladium	-0.635	-0.570	-0.206	-0.089	0.970		0.417	0.305	-0.180	0.100	-0.166	-0.091	0.116	-0.041	-0.079	-0.356	0.027	-0.004	0.002	-0.131
	(0.00)	(0.00)	(0.00)	(0.13)	(0.00)		(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.02)	(0.00)	(0.30)	(0.05)	(0.00)	(0.49)	(0.91)	(0.95)	(0.00)
(7) platinum	0.635	0.684	0.583	0.306	-0.447	-0.341		0.720	0.494	0.149	0.445	0.463	0.677	0.441	0.358	0.029	0.578	0.241	0.506	0.535
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.47)	(0.00)	(0.00)	(0.00)	(0.00)
(8) silver	0.361	0.380	0.130	-0.038	-0.472	-0.434	0.529		0.555	0.317	0.406	0.412	0.460	0.647	0.441	0.399	0.735	0.245	0.445	0.503
	(0.00)	(0.00)	(0.03)	(0.52)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(9) chromium	0.732	0.493	0.315	0.114	-0.855	-0.854	0.457	0.328		0.150	0.696	0.467	0.646	0.568	0.569	0.610	0.642	0.529	0.468	0.672
	(0.00)	(0.00)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(10) cobalt	-0.061	-0.357	-0.065	-0.060	0.546	0.568	-0.082	-0.335	-0.186		-0.033	-0.057	0.151	0.067	-0.087	-0.032	0.167	-0.323	-0.166	0.083
	(0.30)	(0.00)	(0.27)	(0.31)	(0.00)	(0.00)	(0.17)	(0.00)	(0.00)		(0.41)	(0.16)	(0.00)	(0.10)	(0.03)	(0.42)	(0.00)	(0.00)	(0.00)	(0.04)
(11) manganese	0.402	-0.010	-0.113	-0.056	-0.500	-0.562	-0.085	-0.111	0.635	-0.101		0.775	0.520	0.614	0.617	0.582	0.568	0.623	0.716	0.880
	(0.00)	(0.87)	(0.06)	(0.35)	(0.00)	(0.00)	(0.15)	(0.06)	(0.00)	(0.09)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(12) molybdenum	-0.131	-0.664	-0.194	-0.409	0.595	0.487	-0.226	-0.318	-0.210	0.480	0.075		0.527	0.747	0.692	0.476	0.641	0.688	0.613	0.877
	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.20)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(13) nickel	0.201	-0.497	-0.149	-0.445	0.168	0.041	-0.087	-0.115	0.234	0.404	0.420	0.805		0.459	0.449	0.091	0.543	0.441	0.413	0.629
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.48)	(0.14)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)
(14) tungsten	-0.191	0.043	0.307	0.476	0.430	0.572	0.102	-0.195	-0.339	0.633	-0.392	0.009	-0.143		0.644	0.624	0.775	0.656	0.443	0.721
	(0.00)	(0.47)	(0.00)	(0.00)	(0.00)	(0.00)	(0.09)	(0.00)	(0.00)	(0.00)	(0.00)	(0.88)	(0.02)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(15) aluminum	-0.195	-0.680	-0.213	-0.517	0.711	0.605	-0.198	-0.255	-0.380	0.514	-0.127	0.934	0.738	0.064		0.745	0.507	0.630	0.374	0.686
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.28)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
(16) magnesium	-0.263	-0.715	-0.256	-0.459	0.779	0.675	-0.279	-0.351	-0.463	0.524	-0.139	0.916	0.684	0.121	0.970		0.493	0.531	0.305	0.546
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.00)	(0.00)	(0.04)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
(17) antimony	0.527	0.908	0.699	0.544	-0.676	-0.564	0.628	0.326	0.513	-0.337	0.045	-0.596	-0.391	0.083	-0.609	-0.657		0.566	0.535	0.671
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.45)	(0.00)	(0.00)	(0.16)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)
(18) bismuth	0.480	0.624	0.515	0.365	-0.428	-0.352	0.481	0.077	0.454	-0.018	0.086	-0.291	-0.197	0.081	-0.370	-0.401	0.609		0.488	0.648
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.19)	(0.00)	(0.76)	(0.15)	(0.00)	(0.00)	(0.17)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)
(19) iron ore	0.662	0.114	0.201	-0.363	-0.390	-0.475	0.400	0.264	0.651	-0.010	0.439	0.395	0.668	-0.424	0.332	0.211	0.182	0.237		0.692
	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.88)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		(0.00)
(20) steel	0.732	0.318	0.186	-0.191	-0.701	-0.771	0.428	0.444	0.803	-0.328	0.607	0.061	0.430	-0.590	-0.043	-0.147	0.351	0.290	0.873	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.30)	(0.00)	(0.00)	(0.47)	(0.01)	(0.00)	(0.00)	(0.00)	

Note: Pearson correlation, *p*-values in parenthesis, lower triangle matrix: 1910 M01 - 1959 M12, upper triangle matrix: 1960M01 - 2011M12.

Table 4: Complete short-run cycles

	number of cycles		time spent in ...		duration (months)			excess index		Brain-Shapiro test	
	peak-to-peak	through-to-through	slump phase	boom phase	mean	min.	max.	slump phase	boom phase	z	z*
non-ferrous metals											
copper[1]	18(13)	17(12)	56.62	43.38	64.72	26	121	0.04	0.03	-2.49***	9.87***
lead[1]	18(14)	19(14)	58.91	41.09	60.47	30	110	0.02	0.06	-1.62	3.49
tin[1]	14(11)	13(10)	55.39	44.61	82.93	31	138	-0.00	0.04	-2.14**	5.38*
zinc[1]	18(12)	18(12)	61.85	38.15	63.78	31	144	0.01	0.06	-0.08	0.20
mean	17.00(12.5)	16.75(12)	58.19	41.83	67.97	29.50	128.25	0.02	0.05		
precious metals											
gold[1]	10(11)	10(11)	62.91	37.09	99.00	30	173	0.01	0.05	-2.19**	7.69**
palladium	14(10)	13(10)	61.73	38.27	63.79	40	130	0.00	0.04	-0.79	0.80
platinum[1]	14(7)	13(6)	57.03	42.97	85.71	34	185	-0.02	-0.01	-0.57	0.39
silver[1]	14(8)	14(8)	60.78	39.22	78.14	29	188	0.04	0.08	-1.13	4.79*
mean	13.00(9.5)	12.50(9.5)	60.61	39.39	81.66	33.25	169.00	0.01	0.04		
steel alloys											
chromium	10(11)	11(11)	70.53	29.47	79.64	29	211	-0.03	0.05	0.26	1.78
cobalt	10(10)	10(10)	58.44	41.56	87.00	38	156	-0.08	0.12	-0.33	2.10
manganese[1]	12(7)	12(6)	62.17	37.83	95.42	38	250	-0.01	0.06	0.91	1.25
molybdenum	8(9)	9(9)	72.35	27.65	96.44	39	227	0.05	0.13	-0.01	0.04
nickel	10(10)	10(10)	61.14	38.86	90.00	46	214	-0.03	0.03	-0.46	4.37
tungsten	13(10)	13(9)	64.91	35.09	75.08	33	212	-0.08	0.01	0.16	2.19
mean	10.50(9.5)	10.83(9.2)	64.92	35.08	87.26	37.17	211.67	-0.03	0.07		
light metals											
aluminum[1]	12(10)	13(10)	63.07	36.93	88.31	42	133	0.02	0.06	-2.58***	9.46***
magnesium	9(8)	8(8)	74.06	25.94	108.75	44	258	-0.01	0.02	0.27	0.30
mean	10.50(9)	10.50(9)	68.56	31.44	98.53	43.00	195.50	0.01	0.04		
electrical metals											
antimony[1]	12(10)	12(10)	69.12	30.88	90.33	27	172	0.11	0.02	-1.75*	3.06
bismuth	8(8)	9(9)	72.24	27.76	99.56	51	130	0.02	0.08	-2.51***	8.24
mean	10.00(9)	10.50(9)	70.68	29.32	94.94	39.00	151.00	0.06	0.05		
others											
iron ore	7(6)	7(6)	73.09	26.91	130.86	61	216	0.00	0.03	-0.52	1.14
steel[1]	12(9)	12(8)	58.09	41.91	91.75	37	205	0.01	0.02	0.12	0.07
mean	9.50(7.5)	9.50(7)	65.69	34.41	111.31	49.00	210.50	0.01	0.03		
overall mean	12.15(9.8)	12.30(9.55)	63.72	36.28	86.58	36.74	178.65	0.05	0.00		

Note: min. = minimum, max. = maximum, Brain-Shapiro test statistics: (z) against the alternative of monotonic hazard functions and (z*) against non-monotonic hazard functions. H_0: the probability of terminating a phase is independent of the duration a time series already spent in this phase; number of cycles for the subsample from 1936 M01 - 2011 M12 in parenthesis; 1: available from 1910 M01 onwards; *: significance at the 0.10 level, **: significance at the 0.05 level, ***: significance at the 0.01 level.

Table 5: Slump phases

	duration (months)			min. amplitude				max amplitude				Spearman corr.	Brain-Shapiro test	
	mean	min.	max.	from	till	log dif.	months	from	till	log dif.	months	coeff.	z	z*
						non-ferrous metals								
copper	35.22	13	82	Feb 1962	Oct 1963	-2.60	21	Dec 1916	Mar 1921	-144.28	52	0.55	0.04	2.15
lead	34.00	15	81	Feb 1942	May 1946	-15.78	52	Jun 1979	Feb 1986	-173.91	81	0.27	0.4	1.02
tin	43.93	15	92	Dec 1969	Jun 1971	-18.19	19	May 1918	Aug 1921	-158.00	40	0.69	-0.23	0.65
zinc	37.16	15	92	Feb 1960	Mar 1963	-15.93	38	Feb 1916	Aug 1921	-209.08	67	0.20	0.52	1.03
mean	37.58	14.50	86.75			-13.13	32.50			-171.32	60.00			
						precious metals								
gold	61.90	16	160	Dec 1934	Sep 1937	-10.63	34	Sep 1980	Feb 1985	-104.25	54	0.20	-0.41	0.83
palladium	37.21	16	113	Dec 1964	Apr 1966	-3.47	17	Jan 2001	Apr 20032	-190.69	28	0.02	0.07	0.76
platinum	48.14	19	87	Feb 1960	Jul 1963	-10.50	42	Feb 1924	Apr 1931	-156.81	87	0.52	-1.66*	3.13
silver	49.50	13	159	Sep 1963	May 1967	-7.57	45	Jan 1980	Mar 1993	-298.91	159	0.23	0.09	0.33
mean	49.19	16.00	129.75			-8.04	34.50			-187.67	82			
						steel alloys								
chromium	54.64	13	173	Jan 1950	Nov 1951	-6.10	23	Jul 1988	May 1999	-154.04	131	0.06	1.06	1.20
cobalt	50.40	13	121	Dec 1951	Oct 1953	-3.77	23	Jan 1979	Nov 1982	-259.15	47	-0.01	0.14	0.07
manganese	59.33	16	196	Jan 1950	Jul 1952	-5.48	31	May 1917	Dec 1921	-221.52	56	0.42	1.24	2.19
molybdenum	67.78	17	164	Jan 1962	Dec 1963	-2.96	24	Jun 1979	Jan 1993	-320.06	164	0.15	-0.30	0.28
nickel	48.73	20	113	Jan 1970	Dec 1971	-5.25	24	May 2007	Mar 2009	-170.56	23	0.00	-0.10	0.64
tungsten	47.92	14	200	Dec 1925	Nov 1927	-16.49	24	Apr 1977	Nov 1986	-220.70	116	0.66	2.27**	5.77*
mean	54.80	15.50	161.17			-6.68	24.83			-224.33	89.50			
						light metals								
aluminum	53.54	19	110	Oct 1950	Jul 1952	-7.98	22	Mar 1916	Nov 1921	-174.59	69	0.23	-0.85	1.21
magnesium	80.75	14	208	Sep 1950	Jul 1952	-9.01	23	Sep 1995	Oct 2001	-107.26	74	0.26	-0.18	0.15
mean	67.14	16.50	159.00			-8.50	22.50			-140.93	71.50			
						electrical metals								
antimony	63.67	14	111	Aug 1964	Feb 1969	-14.40	55	Mar 1916	Mar 1922	-281.73	73	0.37	-1.38	3.48
bismuth	70.78	26	116	Jan 1950	Oct 1953	-13.88	46	Jul 1974	Jan 1983	-241.16	103	-0.11	-1.40	2.61
mean	67.22	20.00	113.50			-14.14	50.50			-261.45	88.00			
						others								
iron ore	83.00	16	203	Jan 1950	Nov 1951	-4.65	23	Feb 1957	Dec 1973	-104.32	203	0.62	0.16	0.17
steel	51.83	13	131	Dec 1950	Jul 1952	-6.58	20	Jul 1917	Mar 1922	-143.36	57	0.41	-0.15	0.04
mean	67.41	14.50	167.00			-5.62	21.50			-123.84	130.00			
overall mean	53.97	15.85	135.60			-9.06	30.30			-191.72	84.20			

Note: min. = minimum, max. = maximum, log dif. = log differences, Spearman corr. coeff. = Spearman correlation coefficient; Brain-Shapiro test statistics: (z) against the alternative of monotonic hazard functions and (z*) against non-monotonic hazard functions. H_0: the probability of terminating a phase is independent of the duration a time series already spent in this phase; *: significance at the 0.10 level, **: significance at the 0.05 level, ***: significance at the 0.01 level.

Table 6: Boom phases

	duration (months)			min amplitude				max. amplitude				Spearman corr.	Brain-Shapiro test	
	mean	min.	max.	from	till	log dif.	months	from	till	log dif.	months	coeff.	z	z*
non-ferrous metals														
copper	30.50	14	79	Jan 1961	Feb 1962	5.56	14	Jun 1972	Apr 1974	184.42	23	0.37	-1.22	10.86***
lead	27.47	13	61	Aug 1958	Sep 1959	16.70	14	Oct 2002	Oct 2007	204.43	61	0.53	-0.02	3.02
tin	40.00	17	84	Aug 1968	Dec 1969	18.30	17	Nov 2005	May 2008	127.12	31	0.64	-0.55	0.73
zinc	26.94	13	64	Feb 1928	Apr 1929	19.38	15	Aug 2002	Dec 2006	167.07	53	0.48	0.51	0.33
mean	31.23	14.25	72.00			14.99	15.00			170.76	42.00			
precious metals														
gold	42.27	14	110	Oct 1953	Nov 1954	1.89	14	Jul 1970	Nov 1974	135.01	53	0.84	0.53	0.48
palladium	27.57	13	51	Aug 1948	Jan 1950	4.17	18	Nov 1996	Jan 2001	208.71	51	0.56	-0.81	1.09
platinum	38.57	14	134	Mar 1993	Apr 1995	19.05	26	Jul 1999	Aug 2010	154.02	134	0.36	1.72*	3.18
silver	33.00	14	80	Oct 1953	Nov 1955	7.77	26	Feb 1931	May 1935	194.55	52	0.54	0.15	0.65
mean	35.35	13.75	93.75			8.22	21.00			173.07	70.00			
steel alloys														
chromium	26.00	13	58	Nov 1951	Jan 1955	15.15	39	Feb 2006	Apr 2008	157.58	27	-0.24	0.40	0.22
cobalt	35.45	14	110	Oct 1953	Nov 1954	9.12	14	Dec 1969	Jan 1979	245.87	110	0.38	1.35	2.13
manganese	36.62	14	126	Feb 1997	Oct 1998	19.24	21	Aug 1914	May 1917	214.01	34	-0.06	0.71	3.74
molybdenum	29.67	13	64	Sep 1937	Apr 1939	5.64	20	Jan 2001	Jun 2005	258.19	54	0.58	0.53	0.56
nickel	39.70	16	102	Sep 1937	Apr 1939	5.64	20	Oct 2001	May 2007	222.33	68	0.22	1.12	1.72
tungsten	29.57	13	49	Nov 1986	Jan 1989	40.36	27	Jan 1922	Dec 1925	183.29	48	0.58	-1.36	2.28
mean	32.84	13.83	84.83			15.86	23.50			213.55	50.83			
light metals														
aluminum	35.77	15	62	Sep 1937	Apr 1939	5.64	20	Nov 1985	Jun 1988	124.79	32	0.04	-0.53	2.81
magnesium	27.89	18	51	Sep 1937	Feb 1939	4.91	18	Dec 2005	Jun 2008	122.34	31	0.68	0.38	0.16
mean	31.83	16.50	56.50			5.73	19.00			123.57	31.50			
electrical metals														
antimony	30.08	13	64	Dec 1953	Nov 1955	14.15	24	Jul 1914	Mar 1916	205.76	21	0.00	0.63	1.54
bismuth	29.78	13	54	Oct 1953	Nov 1954	1.12	14	Mar 2003	Jun 2007	170.92	52	0.23	-0.19	0.39
mean	29.93	13.00	59.00			7.64	19.00			188.34	36.50			
others														
iron ore	39.29	14	70	Nov 1994	Jan 1996	8.40	15	Mar 2003	Dec 2008	141.46	70	0.18	-0.31	2.20
steel	40.46	14	88	Feb 1999	Mar 2000	9.98	14	Dec 1914	Jul 1917	121.84	32	0.23	-0.36	0.42
mean	39.88	14.00	79.00			9.19	14.50			131.65	51.00			
overall mean	33.33	14.10	78.05			11.61	19.55			177.19	51.85			

Note: min. = minimum, max. = maximum, log dif. = log differences, Spearman corr. coeff. = Spearman correlation coefficient; Brain-Shapiro test statistics: (z) against the alternative of monotonic hazard functions and (z*) against non-monotonic hazard functions. H_0: the probability of terminating a phase is independent of the duration a time series already spent in this phase; *: significance at the 0.10 level, **: significance at the 0.05 level, ***: significance at the 0.01 level.

Figure 1: Average duration of slump and boom phases

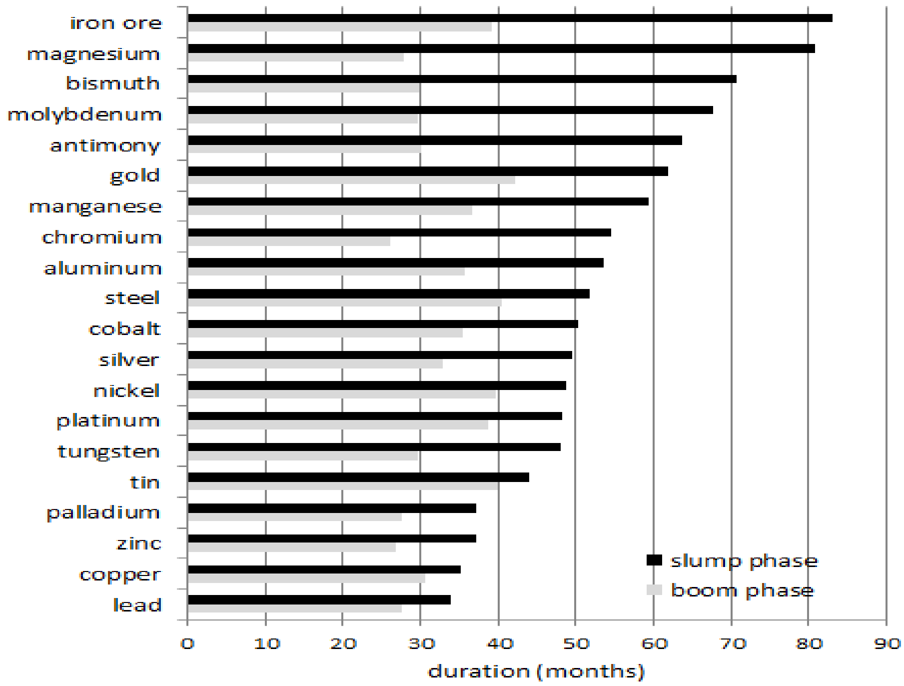


Figure 2: Histogram - duration of booms

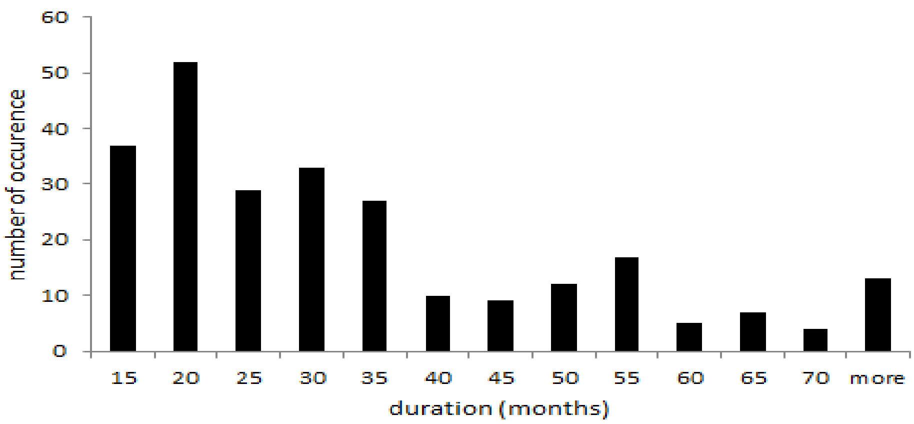


Figure 3: Histogram - duration of slumps

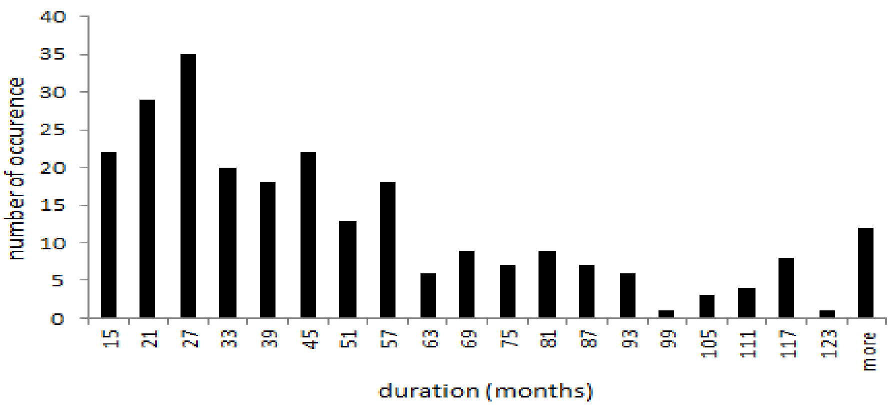


Table 7: Correlation analysis of super cycle components - full sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) copper																				
(2) lead	0.777																			
	(0.00)																			
(3) tin	0.949	0.862																		
	(0.00)	(0.00)																		
(4) zinc	0.729	0.838	0.704																	
	(0.00)	(0.00)	(0.00)																	
(5) gold	0.482	0.654	0.707	0.400																
	(0.00)	(0.00)	(0.00)	(0.00)																
(6) palladium	0.210	0.210	0.306	0.173	0.394															
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)															
(7) platinum	0.754	0.688	0.705	0.570	0.180	0.012														
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.72)														
(8) silver	0.935	0.865	0.987	0.653	0.685	0.278	0.761													
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
(9) chromium	0.833	0.722	0.830	0.578	0.543	-0.232	0.686	0.835												
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)												
(10) cobalt	0.018	0.548	0.242	0.321	0.636	0.199	-0.158	0.235	0.102											
	(0.59)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)											
(11) manganese	0.559	0.565	0.599	0.459	0.222	0.102	0.849	0.615	0.492	-0.137										
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)										
(12) molybdenum	0.670	0.432	0.604	0.365	0.055	0.491	0.759	0.623	0.302	-0.318	0.724									
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
(13) nickel	0.812	0.462	0.788	0.313	0.388	0.455	0.685	0.795	0.575	-0.266	0.604	0.856								
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
(14) tungsten	0.699	0.827	0.809	0.756	0.714	0.672	0.419	0.759	0.424	0.511	0.433	0.522	0.558							
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
(15) aluminum	0.550	0.131	0.553	-0.148	0.316	0.284	0.379	0.587	0.425	-0.299	0.313	0.587	0.842	0.212						
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)						
(16) magnesium	0.594	0.366	0.669	0.082	0.689	0.085	0.179	0.674	0.678	0.184	0.030	0.116	0.569	0.336	0.745					
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.36)	(0.00)	(0.00)	(0.00)	(0.00)					
(17) antimony	0.930	0.900	0.952	0.863	0.605	0.348	0.705	0.915	0.742	0.257	0.627	0.631	0.702	0.882	0.339	0.442				
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
(18) bismuth	0.644	0.248	0.426	0.456	-0.232	0.282	0.572	0.403	0.268	-0.519	0.392	0.803	0.668	0.343	0.348	-0.10	0.534			
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.77)	(0.00)			
(19) iron ore	0.404	0.281	0.414	0.119	0.067	-0.101	0.775	0.457	0.464	-0.395	0.904	0.630	0.594	0.095	0.456	0.090	0.359	0.313		
	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)		
(20) steel	0.774	0.408	0.675	0.350	0.050	0.090	0.801	0.684	0.583	-0.444	0.764	0.863	0.849	0.339	0.685	0.330	0.641	0.737	0.758	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.13)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	

Note: Pearson correlation, p-values in parenthesis.

Table 8: Correlation analysis of super cycle components - subsamples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) copper		0.943 (0.00)	0.942 (0.00)	0.987 (0.00)	0.831 (0.00)	0.360 (0.00)	0.818 (0.00)	0.931 (0.00)	0.883 (0.00)	0.471 (0.00)	0.699 (0.00)	0.550 (0.00)	0.845 (0.00)	0.894 (0.00)	0.918 (0.00)	0.706 (0.00)	0.968 (0.00)	0.448 (0.00)	0.491 (0.00)	0.771 (0.00)
(2) lead	0.822 (0.00)		0.984 (0.00)	0.937 (0.00)	0.897 (0.00)	0.408 (0.00)	0.788 (0.00)	0.984 (0.00)	0.831 (0.00)	0.639 (0.00)	0.670 (0.00)	0.533 (0.00)	0.768 (0.00)	0.919 (0.00)	0.920 (0.00)	0.779 (0.00)	0.954 (0.00)	0.273 (0.00)	0.410 (0.00)	0.719 (0.00)
(3) tin	0.707 (0.00)	0.931 (0.00)		0.913 (0.00)	0.890 (0.00)	0.425 (0.00)	0.881 (0.00)	0.997 (0.00)	0.855 (0.00)	0.503 (0.00)	0.771 (0.00)	0.604 (0.00)	0.841 (0.00)	0.915 (0.00)	0.973 (0.00)	0.732 (0.00)	0.967 (0.00)	0.322 (0.00)	0.563 (0.00)	0.793 (0.00)
(4) zinc	0.591 (0.00)	0.917 (0.00)	0.976 (0.00)		0.778 (0.00)	0.426 (0.00)	0.756 (0.00)	0.898 (0.00)	0.812 (0.00)	0.527 (0.00)	0.658 (0.00)	0.561 (0.00)	0.817 (0.00)	0.918 (0.00)	0.860 (0.00)	0.666 (0.00)	0.961 (0.00)	0.488 (0.00)	0.394 (0.00)	0.755 (0.00)
(5) gold	-0.957 (0.00)	-0.892 (0.00)	-0.712 (0.00)	-0.644 (0.00)		-0.014 (0.72)	0.661 (0.00)	0.921 (0.00)	0.934 (0.00)	0.658 (0.00)	0.452 (0.00)	0.180 (0.00)	0.547 (0.00)	0.656 (0.00)	0.866 (0.00)	0.953 (0.00)	0.772 (0.00)	-0.101 (0.01)	0.340 (0.00)	0.449 (0.00)
(6) palladium	-0.837 (0.00)	-0.513 (0.00)	-0.253 (0.00)	-0.135 (0.02)	0.842 (0.00)		0.522 (0.00)	0.365 (0.00)	-0.061 (0.13)	-0.007 (0.87)	0.699 (0.00)	0.915 (0.00)	0.648 (0.00)	0.718 (0.00)	0.358 (0.00)	-0.236 (0.00)	0.558 (0.00)	0.769 (0.00)	0.390 (0.00)	0.759 (0.00)
(7) platinum	0.958 (0.00)	0.935 (0.00)	0.792 (0.00)	0.730 (0.00)	-0.992 (0.00)	-0.772 (0.00)		0.857 (0.00)	0.736 (0.00)	0.038 (0.34)	0.960 (0.00)	0.794 (0.00)	0.961 (0.00)	0.821 (0.00)	0.946 (0.00)	0.408 (0.00)	0.890 (0.00)	0.549 (0.00)	0.879 (0.00)	0.935 (0.00)
(8) silver	0.983 (0.00)	0.911 (0.00)	0.803 (0.00)	0.718 (0.00)	-0.975 (0.00)	-0.766 (0.00)	0.989 (0.00)		0.873 (0.00)	0.542 (0.00)	0.729 (0.00)	0.545 (0.00)	0.800 (0.00)	0.886 (0.00)	0.968 (0.00)	0.779 (0.00)	0.947 (0.00)	0.248 (0.00)	0.531 (0.00)	0.746 (0.00)
(9) chromium	0.557 (0.00)	0.060 (0.31)	-0.179 (0.00)	-0.324 (0.00)	-0.499 (0.00)	-0.884 (0.00)	0.401 (0.00)	0.420 (0.00)		0.422 (0.00)	0.530 (0.00)	0.227 (0.00)	0.657 (0.00)	0.622 (0.00)	0.891 (0.00)	0.860 (0.00)	0.788 (0.00)	0.089 (0.03)	0.499 (0.00)	0.534 (0.00)
(10) cobalt	0.430 (0.00)	-0.109 (0.07)	-0.317 (0.00)	-0.469 (0.00)	-0.343 (0.00)	-0.787 (0.00)	0.242 (0.00)	0.275 (0.00)	0.984 (0.00)		-0.108 (0.01)	-0.142 (0.00)	0.019 (0.64)	0.444 (0.00)	0.322 (0.00)	0.776 (0.00)	0.414 (0.00)	-0.328 (0.00)	-0.414 (0.00)	-0.021 (0.59)
(11) manganese	0.581 (0.00)	0.415 (0.00)	0.577 (0.00)	0.477 (0.00)	-0.380 (0.00)	-0.167 (0.00)	0.452 (0.00)	0.559 (0.00)	0.042 (0.47)	0.023 (0.70)		0.920 (0.00)	0.962 (0.00)	0.804 (0.00)	0.832 (0.00)	0.166 (0.00)	0.823 (0.00)	0.695 (0.00)	0.894 (0.00)	0.979 (0.00)
(12) molybdenum	-0.071 (0.23)	-0.617 (0.00)	-0.717 (0.00)	-0.835 (0.00)	0.207 (0.00)	-0.325 (0.00)	-0.300 (0.00)	-0.246 (0.00)	0.725 (0.00)	0.835 (0.00)	-0.070 (0.24)		0.874 (0.00)	0.792 (0.00)	0.615 (0.00)	-0.100 (0.01)	0.720 (0.00)	0.839 (0.00)	0.717 (0.00)	0.942 (0.00)
(13) nickel	-0.020 (0.73)	-0.571 (0.00)	-0.689 (0.00)	-0.811 (0.00)	0.149 (0.01)	-0.384 (0.00)	-0.246 (0.00)	-0.195 (0.00)	0.768 (0.00)	0.868 (0.00)	-0.074 (0.21)	0.998 (0.00)		0.879 (0.00)	0.884 (0.00)	0.295 (0.00)	0.916 (0.00)	0.740 (0.00)	0.816 (0.00)	0.985 (0.00)
(14) tungsten	-0.947 (0.00)	-0.673 (0.00)	-0.464 (0.00)	-0.351 (0.00)	0.930 (0.00)	0.959 (0.00)	-0.892 (0.00)	-0.900 (0.00)	-0.762 (0.00)	-0.647 (0.00)	-0.404 (0.00)	-0.163 (0.01)	-0.218 (0.00)		0.846 (0.00)	0.474 (0.00)	0.969 (0.00)	0.591 (0.00)	0.484 (0.00)	0.880 (0.00)
(15) aluminum	-0.060 (0.31)	-0.607 (0.00)	-0.706 (0.00)	-0.829 (0.00)	0.197 (0.00)	-0.337 (0.00)	-0.291 (0.00)	-0.236 (0.00)	0.735 (0.00)	0.844 (0.00)	-0.075 (0.21)	0.999 (0.00)	0.998 (0.00)	-0.171 (0.00)		0.680 (0.00)	0.937 (0.00)	0.348 (0.00)	0.715 (0.00)	0.824 (0.00)
(16) magnesium	-0.103 (0.08)	-0.642 (0.00)	-0.734 (0.00)	-0.849 (0.00)	0.240 (0.00)	-0.291 (0.00)	-0.332 (0.00)	-0.277 (0.00)	0.700 (0.00)	0.815 (0.00)	-0.075 (0.20)	0.999 (0.00)	0.995 (0.00)	-0.129 (0.03)	0.998 (0.00)		0.594 (0.00)	-0.316 (0.00)	0.064 (0.11)	0.180 (0.00)
(17) antimony	0.525 (0.00)	0.867 (0.00)	0.972 (0.00)	0.989 (0.00)	-0.560 (0.00)	-0.043 (0.47)	0.654 (0.00)	0.651 (0.00)	-0.397 (0.00)	-0.527 (0.00)	0.475 (0.00)	-0.856 (0.00)	-0.837 (0.00)	-0.258 (0.00)	0.847 (0.00)	-0.867 (0.00)		0.537 (0.00)	0.578 (0.00)	0.880 (0.00)
(18) bismuth	0.779 (0.00)	0.955 (0.00)	0.808 (0.00)	0.801 (0.00)	-0.903 (0.00)	-0.608 (0.00)	0.916 (0.00)	0.862 (0.00)	0.177 (0.00)	-0.000 (0.99)	0.154 (0.01)	-0.550 (0.00)	-0.495 (0.00)	-0.693 (0.00)	-0.536 (0.00)	-0.579 (0.00)	0.742 (0.00)		0.536 (0.00)	0.783 (0.00)
(19) iron ore	0.212 (0.00)	-0.349 (0.00)	-0.525 (0.00)	-0.663 (0.00)	-0.106 (0.07)	-0.611 (0.00)	0.002 (0.97)	0.043 (0.47)	0.908 (0.00)	0.967 (0.00)	-0.033 (0.58)	0.947 (0.00)	0.966 (0.00)	-0.452 (0.00)	0.951 (0.00)	0.935 (0.00)	-0.710 (0.00)	-0.252 (0.00)		0.807 (0.00)
(20) steel	0.870 (0.00)	0.437 (0.00)	0.291 (0.00)	0.129 (0.03)	-0.757 (0.00)	-0.903 (0.00)	0.715 (0.00)	0.768 (0.00)	0.848 (0.00)	0.789 (0.00)	0.526 (0.00)	0.428 (0.00)	0.472 (0.00)	-0.932 (0.00)	0.427 (0.00)	0.400 (0.00)	0.059 (0.32)	0.417 (0.00)	0.652 (0.00)	

Note: Pearson correlation coefficients, *p*-values in parenthesis.

Table 9: Descriptive statistics - super cycle components

	super cycle		log dif.		duration (months)		
	trough-to-trough	peak	boom	slump	cycle	boom	slump
copper	? - 1931M01	1914M01	-	-80.83	-	-	195
	1931M01 - 1956M08	1946M05	23.73	-3.56	309	185	124
	1956M08 - 1997M12	1977M05	41.77	-76.42	498	250	248
	1997M12 - ?	-	-	-	-	-	-
lead	? - 1936M06	1916M01	-	-48.49	-	-	246
	1936M06 - 1964M06	1950M07	52.20	-69.58	333	170	163
	1964M06 - 1996M04	1979M03	104.04	-110.85	389	183	206
	1996M04 - ?	-	-	-	-	-	-
tin	? - 1928M08	1913M02	-	-43.90	-	-	187
	1928M08 - 1961M10	1941M03	17.73	-15.30	300	152	248
	1961M10 - 1996M12	1979M11	78.33	-136.88	424	218	206
	1996M12 - ?	-	-	-	-	-	-
zinc	? - 1932M01	1914M12	-	-73.39	-	-	206
	1932M01 - 1961M05	1947M12	60.25	-38.69	354	192	162
	1961M05 - 1998M08	1975M08	35.20	-40.02	449	172	277
	1998M08 - ?	-	-	-	-	-	-
chromium	? - 1940M09	-	-	-	-	-	-
	1940M09 - 1964M04	1954M01	20.92	-6.64	285	161	124
	1964M04 - 1999M09	1983M10	30.25	-70.44	427	235	192
	1999M09 - ?	-	-	-	-	-	-
cobalt	? - 1942M07	-	-	-	-	-	-
	1942M07 - 1965M05	1950M02	6.76	-66.89	276	96	180
	1950M02 - 1990M11	1979M07	80.94	-30.37	308	171	137
	1990M11 - 2010M02	1997M11	7.20	-27.45	233	85	148
	2010M02 - ?	-	-	-	-	-	-
manganese	? - 1931M01	1917M03	-	-37.78	-	-	167
	1931M01 - 1970M06	1957M10	42.66	-26.02	475	322	153
	1970M06 - 1994M09	1980M11	21.92	-54.15	293	126	167
	1994M09 - ?	2010M07	71.59	-	-	191	-
molybdenum	? - 1946M12	-	-	-	-	-	-
	1946M12 - 1992M11	1975M04	87.28	-156.26	553	341	212
	1992M11 - ?	2008M10	168.49	-	-	192	-
nickel	? - 1949M10	1933M10	-	-37.08	-	-	193
	1949M10 - 1995M11	1978M03	42.42	-55.66	555	342	213
	1995M11 - ?	-	-	-	-	-	-
tungsten	? - 1923M11	-	-	-	-	-	-
	1923M11 - 1962M02	1942M03	99.89	-101.18	461	221	240
	1962M02 - 1994M02	1977M06	142.44	-148.34	386	185	201
	1994M02 - ?	-	-	-	-	-	-

	super cycle		log. dif.		duration (months)		
	trough-to-trough	peak	boom	slump	cycle	boom	slump
gold	? - 1924M07	1911M11	-	-53.69	-	-	153
	1924M07 - 1965M12	1938M12	84.09	-89.69	499	174	325
	1965M12 - 1998M01	1982M06	106.21	-108.15	387	199	188
	1998M01 - ?	-	-	-	-	-	-
palladium	? - 1956M03	1939M05	-	-65.78	-	-	203
	1956M03 - 1990M09	1976M02	53.29	-50.62	416	240	176
	1990M09 - ?	2004M10	54.39	-	-	170	-
platinum	? - 1937M03	1921M06	-	-87.35	-	-	190
	1937M03 - 1967M05	1955M01	47.51	-3.49	364	215	149
	1967M05 - 1995M08	1980M12	21.11	-69.87	341	164	177
	1995M08 - ?	2009M09	79.79	-	-	170	-
silver	? - 1932M05	1916M07	-	-63.24	-	-	191
	1932M05 - 1965M12	-	-	-	-	-	-
	1965M12 - 1996M06	1980M05	81.99	-142.64	368	174	194
	1996M06 - ?	-	-	-	-	-	-
aluminum	? - 1925M09	1914M06	-	-31.61	-	-	136
	1925M09 - 1949M01	1936M01	26.82	-53.54	282	125	157
	1949M01 - 1971M06	1962M10	50.70	-11.38	271	166	105
	1971M06 - 1995M08	1981M01	12.74	-37.27	292	116	176
	1995M06 - ?	2010M07	25.93	-	-	180	-
magnesium	? - 1949M08	-	-	-	-	-	-
	1949M08 - 1968M07	1962M08	34.34	-4.04	229	157	72
	1968M07 - 2001M03	1982M12	39.49	-68.92	514	174	340
	2001M03 - ?	-	-	-	-	-	-
antimony	? - 1928M12	1912M05	-	-68.95	-	-	200
	1928M12 - 1961M10	1947M10	47.09	-36.41	396	227	169
	1961M10 - 1996M12	1977M08	71.96	-110.24	424	191	233
	1996M12 - ?	-	-	-	-	-	-
bismuth	? - 1938M11	-	-	-	-	-	-
	1938M11 - 1956M08	1949M01	22.41	-10.69	215	123	92
	1956M08 - 1988M10	1970M11	73.99	-91.95	388	172	216
	1988M10 - ?	-	-	-	-	-	-
iron ore	? - 1944M06	1933M04	-	-9.58	-	-	135
	1944M06 - 1972M11	1959M09	53.27	-54.33	343	184	159
	1972M11 - 1995M10	1983M03	32.02	-62.86	277	125	152
	1995M10 - ?	2010m05	99.77	-	-	176	-
steel	? - 1929M08	1914M06	-	-39.51	-	-	183
	1929M08-1946M06	1938M03	7.08	-6.01	201	104	97
	1946M06 - 1972M01	1962M07	35.20	-6.41	312	197	115
	1972M01 - 1995M03	1977M03	1.36	-50.16	280	63	217
	1995M03 - ?	-	-	-	-	-	-

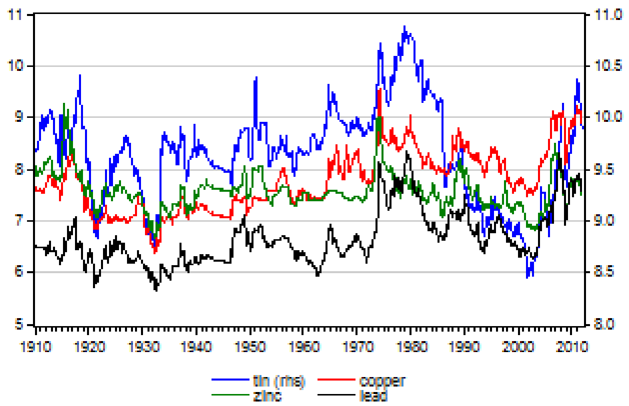
Note: log dif. = log differences.

Table 10: Long-run trend

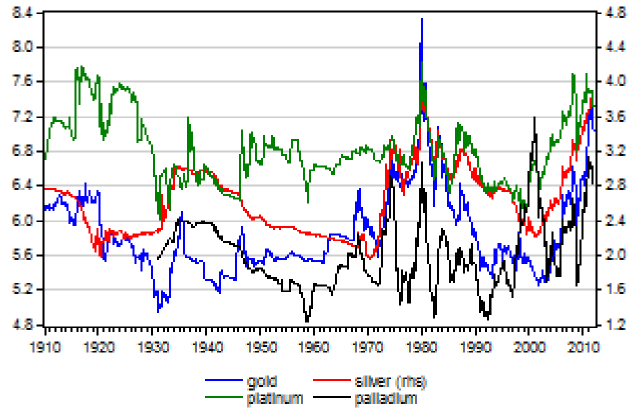
	deviation from long-run trend (%)				trend				
	mean	st.dev.	min.	max.	downward	upward	downward	upward	total
copper	1.81	38.07	-87.47	107.86		1910-2011			1910-2011
total growth						133.28			133.28
annual growth						1.32			1.32
lead	0.98	40.29	-83.17	135.51		1910-2011			1910-2011
total growth						99.46			99.46
annual growth						0.98			0.98
tin	-1.72	39.07	-93.26	95.59	1910-1926	1926-1970	1970-2011		1910-2011
total growth					-10.28	41.33	-56.66		-25.61
annual growth					-0.64	0.92	-1.36		-0.25
zinc	1.02	33.44	-79.04	135.31	1910-1946	1946-1979	1979-2011		1910-2011
total growth					-18.95	8.14	-16.16		-26.97
annual growth					-0.53	0.24	-0.49		-0.27
gold	0.75	36.45	-65.06	114.15		1910-2011			1910-2011
total growth						48.73			48.73
annual growth						0.48			0.48
palladium	3.95	31.52	-69.82	119.63	1931-1968	1968-2011			1931-2011
total growth					-17.33	34.92			17.59
annual growth					-0.47	0.79			0.22
platinum	2.66	32.07	-62.45	86.57	1910-1963	1963-1998	1998-2011		1910-2011
total growth					-45.20	14.20	-3.99		-35.00
annual growth					-0.85	0.40	-0.29		-0.35
silver	1.46	40.97	-76.46	159.30	1910-1944	1944-1990	1990-2011		1910-2011
total growth					-17.30	51.14	-8.93		24.92
annual growth					-0.51	1.10	-0.41		0.25
chromium	-2.83	25.80	-89.09	99.53		1934-1975	1975-2011		1934-2011
total growth						19.76	-16.50		3.26
annual growth						0.48	-0.45		0.04
cobalt	1.53	35.93	-102.47	171.3		1936-2011			1936-2011
total growth						42.76			42.76
annual growth						0.57			0.57
manganese	-0.88	34.66	-71.61	125.02	1910-2011				1910-2011
total growth					-87.59				-87.59
annual growth					-0.87				-0.87
molybdenum	-1.03	51.26	-107.90	157.59	1934-2011				1934-2011
growth rate					-169.84				-169.84
annual growth					-2.21				-2.21
nickel	0.17	28.07	-89.69	115.40		1929-2011			1929-2011
total growth						39.25			39.25
annual growth						0.48			0.48
tungsten	-4.73	54.39	-187.18	121.85	1917-1925	1925-1955	1955-2011		1917-2011
total growth					-0.49	23.06	-107.11		-84.54
annual growth					-0.06	0.75	-1.88		-0.90
aluminum	1.33	25.19	-49.06	116.60	1910-2011				1910-2011
total growth					-154.52				-154.52
annual growth					-1.53				-1.53
magnesium	-2.60	23.86	-56.39	52.63	1934-2011				1934-2011
total growth					-132.18				-132.18
annual growth					-1.72				-1.72
antimony	-1.31	46.22	-107.48	171.31		1910-1976	1976-2007	2007-2011	1910-2011
total growth						83.25	-17.38	2.10	67.98
annual growth						1.26	-0.55	0.47	0.67
bismuth	-2.64	36.54	-100.06	111.97	1934-2011				1934-2011
total growth					-113.85				-113.85
annual growth					-1.48				-1.06
iron ore	0.82	31.70	-42.82	185.56	1929-2011				1929-2011
total growth					-86.86				-86.86
annual growth					-1.06				-1.06
steel	-0.93	24.77	-58.89	77.03		1921-1973	1973-2008	2008-2011	1921-2011
total growth						53.45	-15.96	1.10	36.34
annual growth						0.85	-0.51	0.33	0.36

Note: total growth = log differences x 100, annual growth = average annual growth rate, st.dev. = standard deviation, min. = minimum, max. = maximum.

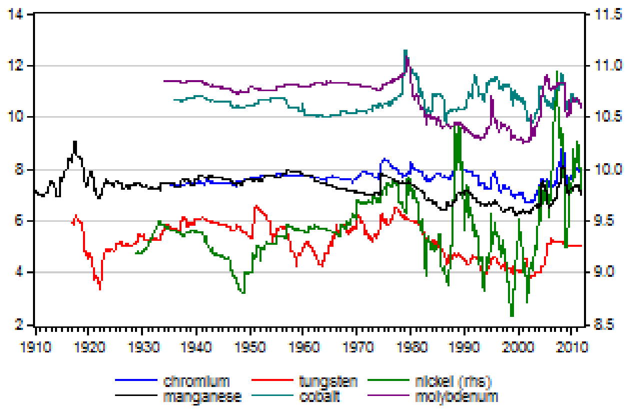
Figure 4: Log metal prices



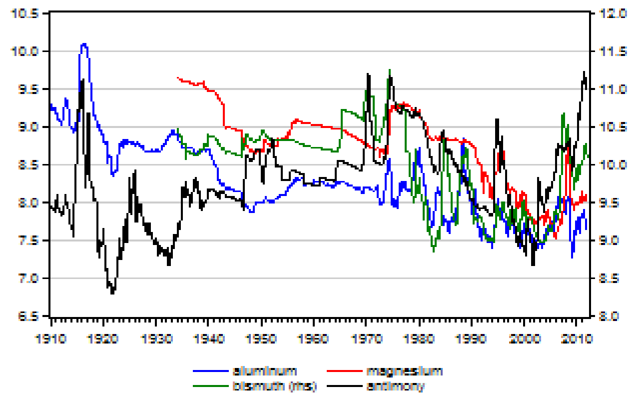
(a) non-ferrous metals



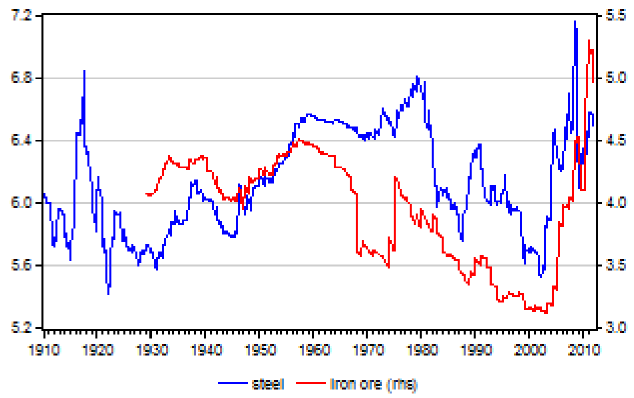
(b) precious metals



(a) steel alloys



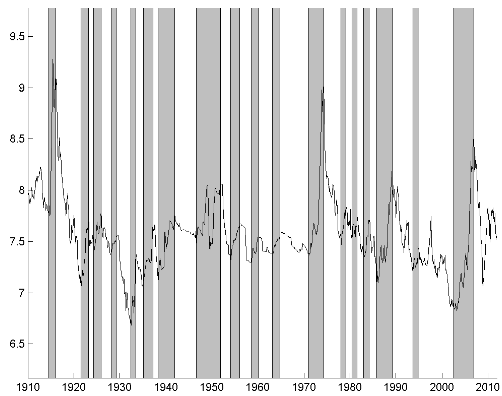
(b) light and electrical metals



(b) steel and iron ore

Figure 5: Short-run cycles - zinc prices

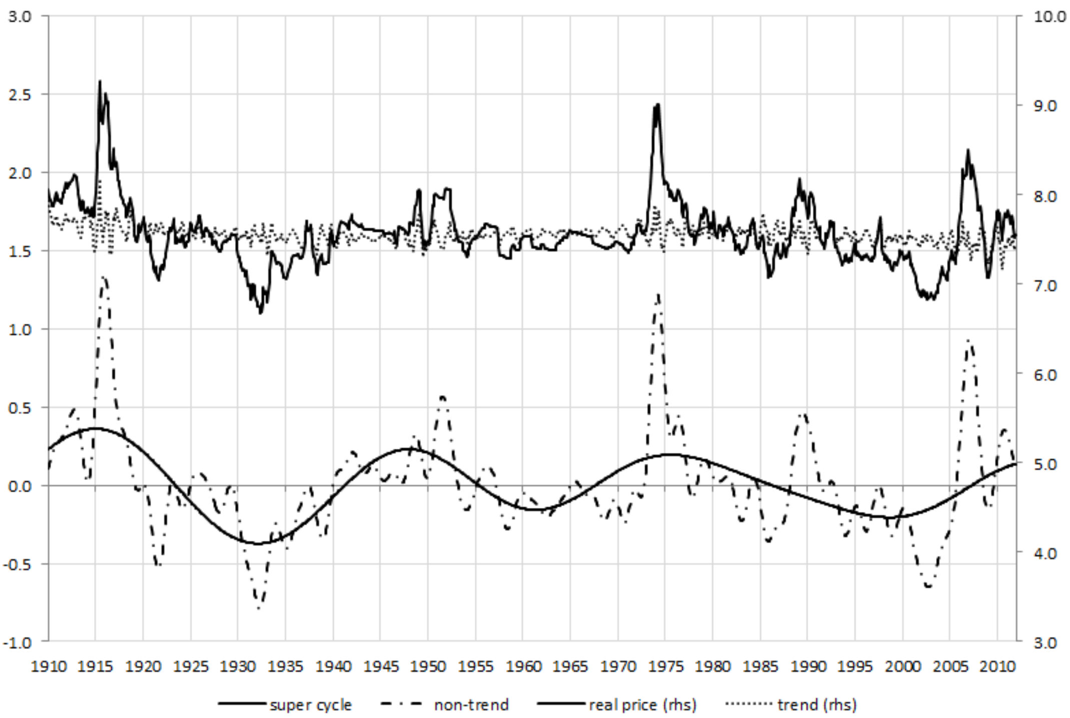
(a) Boom and slump phases



(b) Durations and amplitudes

Note: Slump phases are denoted by the shaded areas and boom phases by the unshaded areas in the left hand side chart, the durations and amplitudes of boom and slump phases are displayed in the right hand side chart.

Figure 6: Super cycle components - zinc prices



Note: log scaling, rhs = right hand side.

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